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Southern Plains Network Vital Signs Monitoring Plan Phase 2 Report

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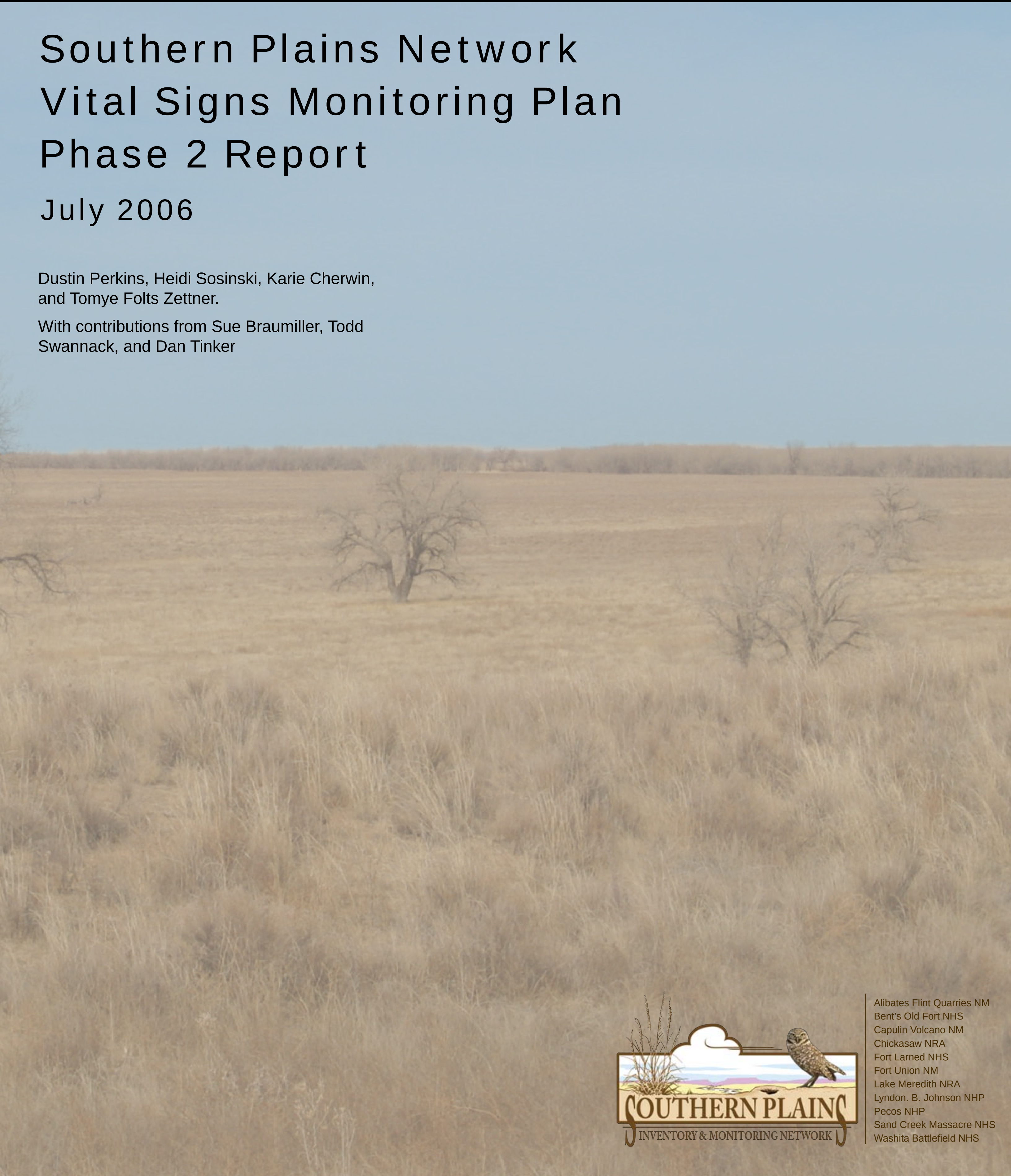

SOUTHERN PLAINS
INVENTORY & MONITORING NETWORK

Alibates Flint Quarries NM
Bent's Old Fort NHS
Capulin Volcano NM
Chickasaw NRA
Fort Larned NHS
Fort Union NM
Lake Meredith NRA
Lyndon. B. Johnson NHP
Pecos NHP
Sand Creek Massacre NHS
Washita Battlefield NHS

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On the Cover

View of the short-grass prairie at Sand Creek Massacre National Historic Site. Photograph by Heidi Sosinski, National Park Service

EXECUTIVE SUMMARY

Knowing the condition of natural resources in national parks is fundamental to the National Park Service's (NPS) ability to manage park resources "unimpaired for the enjoyment of future generations". The NPS has implemented a strategy to programmatically institutionalize natural resource monitoring that will ensure that parks possess scientific information needed for effective decision-making and resource protection. The effort includes 270 park units with significant natural resources. These parks have been grouped into 32 monitoring networks linked by geographic location and ecological similarities. The network organization will facilitate collaboration, information sharing, and economies of scale in natural resource monitoring. Parks within each of the 32 networks collaborate and share funding and professional staff to plan, design, and implement an integrated long-term monitoring program.

The Southern Plains Inventory and Monitoring Network (SOPN) is composed of eleven NPS units within the states of Colorado, Kansas, New Mexico, Oklahoma, and Texas. The member parks are Alibates Flint Quarries National Monument, Bent's Old Fort National Historic Site, Capulin Volcano National Monument, Chickasaw National Recreation Area, Fort Larned National Historic Site, Fort Union National Monument, Lake Meredith National Recreation Area, Lyndon B. Johnson National Historical Park, Pecos National Historical Park, Sand Creek Massacre National Historic Site, and Washita Battlefield National Historic Site.

The complex task of developing ecological monitoring requires a front-end investment in planning and design to ensure that monitoring will meet the most critical information needs and produce ecologically relevant and scientifically credible data that are accessible to managers in a timely manner. The SOPN monitoring program is being developed over five years with specific objectives and reporting requirements for each of three planning phases. The first planning step involved compiling and organizing relevant science information and conducting detailed park scoping to identify the most important resources and issues for each park. A second step was to collaborate with regional scientists to develop conceptual ecological models of the predominant SOPN ecosystems. The network then held several workshops in 2004 and 2005 to identify and evaluate vital signs for long-term monitoring. During these workshops park managers, subject-matter experts from the scientific community, and SOPN staff identified and evaluated resources and potential indicators as candidates for monitoring. Following those workshops, the SOPN Technical Committee and the Board of Directors met to make the final selection of network vital signs. The diversity of ecosystems in SOPN parks, the geographic distribution of these parks, and differences in resource management priorities among parks are challenges facing the network. However, the vital signs selection process found that parks share a number of similar resource management issues and monitoring needs. The SOPN has identified 29 vital signs that would represent a comprehensive monitoring program. However, the current level of funding will not enable SOPN to monitor all 29 vital signs. Therefore, SOPN has identified 11 core vital signs that will represent the majority of our program in the near future. We have fully integrated our water quality monitoring within the SOPN monitoring program.

This document is the second of three scheduled reports that precede the final SOPN monitoring plan. This Phase II Vital Signs Monitoring Report includes: 1) monitoring goals and the planning process used to develop the monitoring program; 2) summaries of existing information concerning park natural resources and resource management issues across the network; 3) a conceptual model framework for SOPN park ecosystems; and 4) descriptions of the prioritization and selection processes for vital signs. The draft of the Phase III report is due December 15, 2007 and will include the above topics as well as: 1) a sampling framework for aquatic and terrestrial ecosystems in parks; 2) monitoring protocols, 3) description of the network's approach to data management, and 4) information on program administration, funding, and operations. The final monitoring plan is due September 31, 2008.

Core Vital Signs organized within the NPS ecological monitoring framework.

Level 1	Level 2	Level 3	Vital Sign
Geology and Soils	Soil Quality	Soil Function and Dynamics	Soil Structure and Chemistry
Water	Hydrology	Ground Water Dynamics	Ground Water Levels
		Surface Water Dynamics	Water Quantity
	Water Quality	Water Chemistry	Core Parameters (pH, dissolved oxygen, conductivity, temperature) + E. Coli
Biological Integrity	Invasive Species	Invasive / Exotic Plants	Early Detection Exotic Plants
	Focal Species or Communities	Wetland Community	Wetland Vegetation Communities
		Grassland / Herbaceous Communities	Grassland Vegetation Communities
		Birds	Bird Communities
Human Use	Non-Point Source Human Effects	Non-Point Source Human Effects	Human Demographics
Landscapes	Fire and Fuel Dynamics	Fire and Fuel Dynamics	Fire and Fuel Dynamics
	Landscape Dynamics	Land Cover and Use	Landscape Dynamics

ACKNOWLEDGEMENTS

The Southern Plains Network (SOPN) has benefited greatly from the “bleeding edge” networks that are developing or have developed their monitoring plans. In particular, SOPN borrowed extensively from the Sonoran Desert, Central Alaska, Cumberland-Piedmont, Greater Yellowstone and Heartland Networks for the development of Chapter 1. SOPN used text from the Northern Colorado Plateau and Southern Colorado Plateau Networks for much of the background information in Chapter 2 and borrowed from the Sonoran Desert, Central Alaskan, and Greater Yellowstone Networks for Chapter 3. All of the Intermountain Region I+M Networks have been enormously helpful as a sounding board and providing advice to our young network. The SOPN Board of Directors and Technical Committee have provided extensive support and guidance. We really appreciate the excitement you have shown for our program. This report has benefited greatly from the thoughtful review of the SOPN Board of Directors and Technical Committee and Tim Seastedt at the University of Colorado. The staff at Lyndon B. Johnson National Historical Park have been gracious hosts to our network in providing excellent office space and administrative support.

TABLE OF CONTENTS

List of Figures

List of Tables

CHAPTER 1. INTRODUCTION AND BACKGROUND

"...that is the way to start, with stones forming a wide circle, marsh marigolds in bloom, hawks hunting mice, boys climbing hills, to sit under the sun, to dream of eagle wings and antelope; words cannot be spoken first."
- Maurice Kenny, Mohawk Nation

The Southern Plains Inventory and Monitoring Network (SOPN) is composed of 11 National Park Units in Colorado, Kansas, New Mexico, Oklahoma and Texas (Table 1.1 and Figure 1.1). SOPN is one of the 32 networks included in the Servicewide Inventory and Monitoring program and one of seven networks in the Intermountain Region. Park units within the SOPN are located in the short-grass and mixed-grass ecosystems, and range in size from 326 acres at Washita Battlefield National Historic Site to 46,349 acres at Lake Meredith National Recreation Area. Detailed natural resource summaries are provided in Appendix A.

1.1 INTEGRATED NATURAL RESOURCE MONITORING

The purposes of the Vital Signs Monitoring Program in the National Park Service (NPS) relate directly to the purposes of the national park system. In this section, the justifications for integrating natural resource monitoring, the legislation policy and guidance that directs the program, the goals of the monitoring program and an overview of the network approach to vital signs monitoring are reviewed.

1.1.1 Justification for Integrated Natural Resource Monitoring

Knowing the condition of natural resources in national parks is fundamental to the Service's ability to manage park resources "unimpaired for the enjoyment of future generations" (Organic Act of 1916, 16 U.S.C. 1 § 1). National Park managers across the country are confronted with increasingly complex and challenging issues that require a broad-based understanding of the status and trends of park resources as a basis for making decisions and working with other agencies and the public for the benefit of park resources. For years, managers and scientists have sought a way to characterize and determine trends in the condition of parks and other protected areas in order to assess the efficacy of management practices and restoration efforts and to provide early warning of impending threats.

The challenge of protecting and managing a park's natural resources requires a multi-agency, ecosystem approach because most parks are open systems, with threats such as air and water pollution, or invasive species, originating outside of the park's boundaries. An ecosystem approach is further needed because no single spatial or temporal scale is appropriate for all system components and processes; the appropriate scale for understanding and effectively managing a resource might be at the population, species, community, or landscape level, and in some cases may require a regional, national or international effort to understand and manage the resource. National parks are part of larger, often altered ecosystems, and must be managed in ways that recognizes the constraints and limitations imposed by the landscape in which the unit is embedded.

Natural resource monitoring is important for two major reasons. First, it provides site-specific information needed to understand and identify changes in complex, variable, and imperfectly understood natural systems. Second, monitoring determines whether observed changes are within natural levels of variability or may be indicators of unwanted human influences. Understanding the dynamic nature of park ecosystems and the consequences of human activities is essential for management decision-making aimed to maintain, enhance, or restore the ecological integrity of park ecosystems and to avoid, minimize, or mitigate ecological threats to these systems (Roman and Barrett 1999).

"Vital signs," as defined by the NPS, are a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values. The elements and processes that are monitored are a subset of the total suite of natural resources that park managers are directed to preserve, include water, air, geological resources, plants and animals, and the various ecological, biological, and physical processes that act on those resources. Information obtained through monitoring can help managers understand how to develop the most effective approach to ecologically sound management and restoration. This is particularly helpful in situations where natural areas have been so highly altered that physical and biological processes no longer operate (e.g., control of fires, dams and reservoirs).

Table 1.1 List of abbreviations, affiliations, and basic statistics for the Southern Plains Inventory and Monitoring Network parks.

Park Name	State	Region	Abbreviation	Year Established	Acres (Hectares)	Base Funding (FY05)	FTE (FY04)	Visitation (FY04)
Alibates Flint Quarries National Monument	Texas	Intermountain	ALFL	1965	1,371 (555)	$0	0	1,794
Bent's Old Fort National Historic Site	Colorado	Intermountain	BEOL	1960	799 (323)	$1,052,000	19	31,487
Capulin Volcano National Monument	New Mexico	Intermountain	CAVO	1916	793 (321)	$651,000	10	58,705
Chickasaw National Recreation Area	Oklahoma	Intermountain	CHIC	1906	9,889 (4,002)	$3,032,000	41	2,939,119
Fort Larned National Historic Site	Kansas	Midwest	FOLS	1964	718 (291)	$941,000	13	35,535
Fort Union National Monument	New Mexico	Intermountain	FOUN	1956	721 (292)	$773,000	13	13,572
Lake Meredith National Recreation Area	Texas	Intermountain	LAMR	1990 *	46,349 (18,757)	$2,150,000	40	806,481
Lyndon B. Johnson National Historical Park	Texas	Intermountain	LYJO	1969	674 (273)	$3,361,000	52	94,963
Pecos National Historical Park	New Mexico	Intermountain	PECO	1965	6,670 (2,699)	$1,324,000	19	34,435
Sand Creek Massacre National Historic Site	Colorado	Intermountain	SAND	2000 ‡	2,400 (971)	$356,000	3	0
Washita Battlefield National Historic Site	Oklahoma	Intermountain	WABA	1965	326 (132)	$640,000	3	15,723
TOTAL					**71,606 (29,878)**	**$14,280,000**	**213**	**4,032,814**

* LAMR has been administered by NPS since 1965, but did not officially become a unit of NPS until 1990.
‡ SAND was authorized in 2000 and has yet to be officially established.

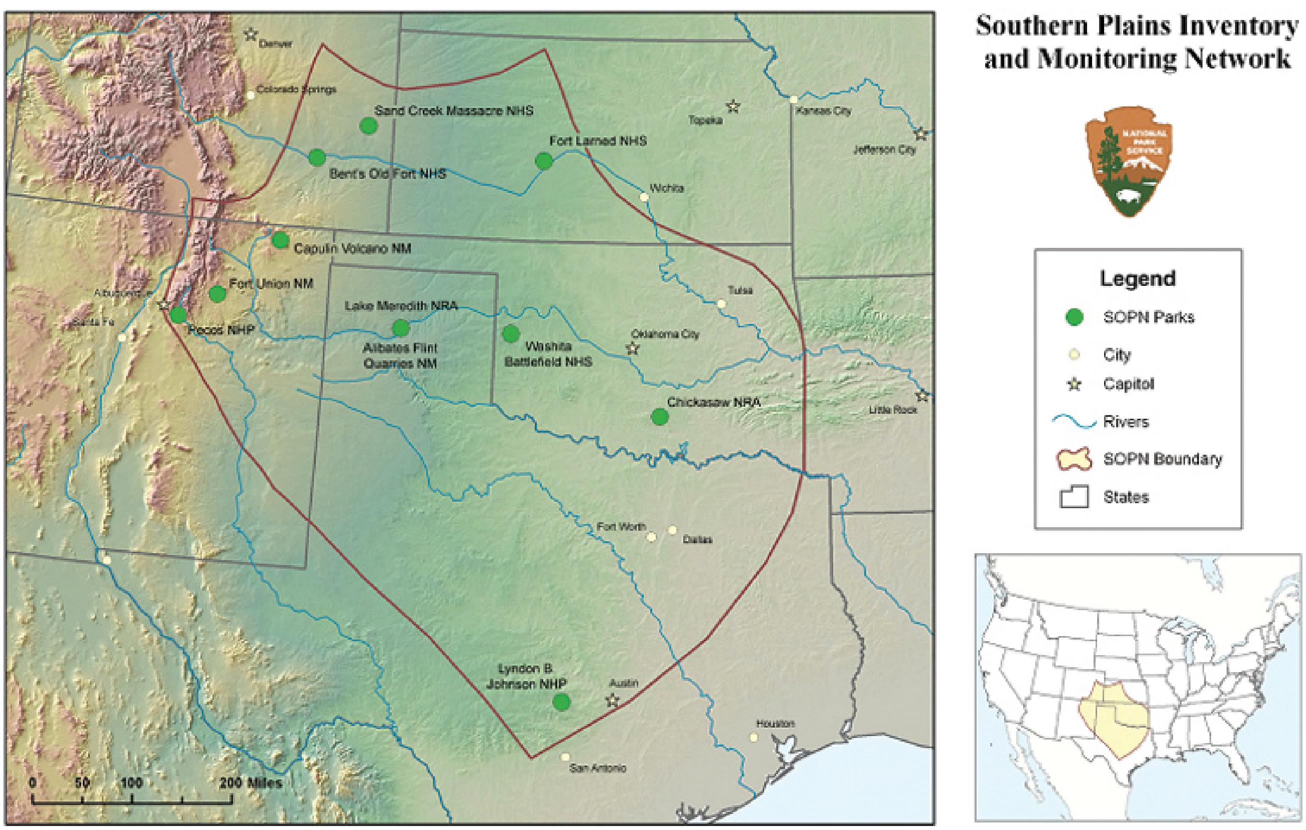

Figure 1.1 Southern Plains Inventory and Monitoring Network

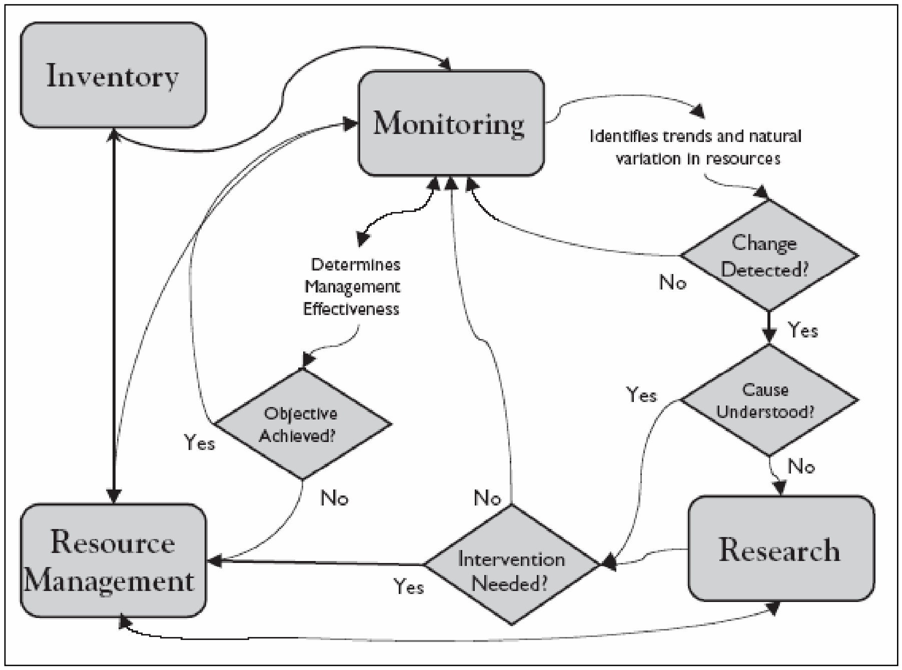

Figure 1.2 Stewardship of natural resources in national parks involves the interconnected activities of inventories, monitoring, research, and resource management (modified from Jenkins et al. 2002)

Monitoring is a central component of natural resource stewardship in the NPS, and in conjunction with natural resource inventories, management, and research, provides the information needed for effective, science-based managerial decision-making and resource protection (Figure 1.2). Natural resource inventories are extensive point-in-time efforts to determine the location or condition of a resource, including the presence, class, distribution, and status of plants, animals, and abiotic components such as water, soils, landforms, and climate. Monitoring differs from inventories by adding the dimension of time; the general purpose of monitoring is to detect changes or trends in a resource. Elzinga et al. (1998) defined monitoring as, "the collection and analysis of repeated observations or measurements to evaluate changes in condition and progress toward meeting a management objective." Detection of a change or trend may trigger a management action, or it may generate a new line of inquiry. Research is generally defined as the systematic collection of data that produces new knowledge or relationships and usually involves an experimental approach, in which a hypothesis concerning the probable cause of an observation is tested in situations with and without the specified cause. A research design is usually required to determine the cause of changes observed by monitoring. The development of monitoring protocols also involves a research component to determine the appropriate spatial and temporal scale for monitoring.

1.1.2 Legislation, Policy and Guidance

In establishing the first national park in 1872, Congress "dedicated and set apart (nearly 1,000,000 acres of land) as a … pleasuring ground for the benefit and enjoyment of the people" (16 U.S.C. 1 § 21). By 1900 a total of five national parks had been established, along with additional historic sites, scenic rivers, recreation areas, monuments, and other designated units. Each unit was to be administered according to its individual enabling legislation, but was created with a common purpose of preserving the "precious" resources for people's benefit. Sixteen years later the passage of the National Park Service Organic Act of 1916 (16 U.S.C. 1 § 1) established and defined the mission of the National Park Service, and through it, Congress implied the need to monitor natural resources and guarantee unimpaired park services:

> *"The service thus established shall promote and regulate the use of the Federal areas known as national parks, monuments, and reservations hereinafter specified … by such means and measures as conform to the fundamental purpose of the said parks, monuments, and reservations, which purpose is to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations."*

Congress reaffirmed the declaration of the Organic Act vis-à-vis the General Authorities Act of 1970 (16 U.S.C. 1a-1a8) and effectively ensured that all park units be united into the 'National Park System' by a common purpose of preservation, regardless of title or designation. In 1978, the National Park Service's protective function was further strengthened when Congress again amended the Organic Act to state "…the protection, management, and administration of these areas shall be conducted in light of the high public value and integrity of the National Park System and shall not be exercised in derogation of the values and purposes for which these various areas have been established…" thus further endorsing natural resource goals of each park. A decade later, park service management policy again reiterated the importance of this protective function of the NPS to "understand, maintain, restore, and protect the inherent integrity of the natural resources" (NPS Management Policies 2001).

More recent and specific requirements for a program of inventory and monitoring park resources are found in the National Parks Omnibus Management Act of 1998 (P.L. 105-391). The intent of the Act is to create an inventory and monitoring program that may be used:

> *"to establish baseline information and to provide information on the long-term trends in the condition of National Park System resources."*

Subsequently, in 2001, NPS management updated previous policy and specifically directed the Service to inventory and monitor natural systems in efforts to inform park management decisions:

> *"Natural systems in the national park system, and the human influences upon them, will be monitored to detect change. The Service will use the results of monitoring and research to understand the detected change and to develop appropriate management actions" (2001 NPS Management Policies).*

In addition to the legislation directing the formation and function of the National Park System, there are several other pieces of legislation intended to not only protect the natural resources within national parks and other federal lands, but to address concerns over the environmental quality of life in the United States generally. Many of these federal laws also require natural resource monitoring within national park units. As NPS units are among some of the most secure areas for numerous threatened, endangered or otherwise compromised natural resources in the country, the particular guidance offered by federal environmental legislation and policy is an important component to the development and administration of a natural resource inventory and monitoring system in the National Parks. Legislation, policy and executive guidance all have an important and direct bearing on the development and implementation of natural resource monitoring in the National Parks. Relevant federal legal mandates are therefore summarized in Appendix B.

GPRA Goals

It is particularly important to note the Government Performance and Results Act (GPRA), because of its central role in agency operations and its relationship to the monitoring program. For NPS, four overarching goals provide direction for developing more specific goals.

1. Category I goals preserve and protect park resources.
2. Category II goals provide for the public enjoyment and visitor experience of parks.
3. Category III goals strengthen and preserve natural and cultural resources and enhance recreational opportunities managed by partners.
4. Category IV goals ensure organizational effectiveness.

The SOPN vital signs monitoring plan clearly assists in meeting numerous Category I goals and augments Category II, III and IV goals. The servicewide goal pertaining to natural resource inventories specifically identifies the objective of inventorying the resources of the parks as an initial step in protecting and preserving park resources (GPRA Goal Ib1). The vital signs monitoring plan identifies the indicators or "vital signs" of the network (GPRA Goal Ib3a) which will be complete for SOPN in Fiscal Year 2006. SOPN plans to implement vital signs monitoring, detecting trends in resource condition (GPRA Goal Ib3b) in Fiscal Year 2008. In addition to the national strategic goals, each park has a five-year plan with specific park GPRA goals, goals relevant to natural resource monitoring and management are presented in Appendix C.

SOPN Park Unit Enabling Legislation

The SOPN includes four National Historic Sites, three National Monuments, two National Historical Parks, and two National Recreation Areas. In 1970, Congress elaborated on the 1916 NPS Organic Act, saying all of these designations have equal legal standing in the National Park system. Definitions for NPS designations are found in Appendix D.

The enabling legislation of an individual park provides insight into the natural and cultural resources and resource values for which it was created to preserve. Along with national legislation, policy and guidance, a park's enabling legislation provides justification and, in some cases, specific guidance for the direction and emphasis of resource management programs, including inventory and monitoring. In some cases the enabling legislation is further interpreted and expanded in park planning documents such as General Management Plans. See Appendix A for a more detailed description of each SOPN park enabling legislation and excerpts from general Management Plans outlined in the individual park natural resource summaries.

1.1.3 Servicewide Goals for Vital Signs Monitoring

The overall goal of natural resource monitoring in parks is to develop scientifically sound information on the current status and long-term trends in the composition, structure, and function of park ecosystems, and to determine how well current management practices are sustaining those ecosystems. The NPS-wide I&M Program has developed the following long-term goals to comply with legal requirements, fully implement NPS policy, and to provide park managers with the data required to understand and manage park resources:

1. Determine status and trends in selected indicators of the condition of park ecosystems to allow managers to make better-informed decisions and to work more effectively with other agencies and individuals for the benefit of park resources.
2. Provide early warning of abnormal conditions and impairment of selected resources to help develop effective mitigation measures and reduce costs of management.
3. Provide data to better understand the dynamic nature and condition of park ecosystems and to provide reference points for comparisons with other, altered environments.
4. Provide data to meet certain legal and congressional mandates related to natural resource protection and visitor enjoyment.
5. Provide a means of measuring progress towards performance goals.

These NPS-wide monitoring goals guide SOPN's program scope and direction. The program will include effects-oriented monitoring to detect changes in the status or condition of selected resources, stress-oriented monitoring to meet certain legal mandates (e.g., Clean Water Act), and effectiveness monitoring to measure progress towards meeting performance goals (Noon et al. 1999, National Research Council 1995). The NPS-wide goals also acknowledge the importance of understanding inherent ecosystem variability in order to interpret human-caused change and recognize the potential role of NPS ecosystems as reference sites for more impaired ecosystems.

An effective monitoring program provides information that can be used in multiple ways. The most widely identified application of monitoring information is that of enabling managers to make better-informed management decisions (White and Bratton 1980, Croze 1982, Jones 1986, Davis 1989, Quinn and van Riper 1990). Another use of monitoring information is to document changes primarily for the sake of familiarity with resources (Croze 1982, Halvorson 1984). By gathering data over long periods, correlations between different attributes become apparent, and resource managers gain a better general understanding of the ecosystem. A third use of monitoring information may be to convince others to make decisions benefiting national parks (Johnson and Bratton 1978, Croze 1982). Monitoring sensitive species, invasive species, culturally significant species, or entire communities can provide park managers, stakeholders, and the public with an early warning of the effects of human activities before they are noticed elsewhere (Davis 1989). Finally, a monitoring program can provide basic background information that is needed by park researchers, public information offices, interpreters, and those wanting to know more about the area around them (Johnson and Bratton 1978).

1.1.4 Network Approach to Vital Signs Monitoring

The NPS strategy to institutionalize inventory and monitoring throughout the agency consists of a framework having three major components: (1) completion of 12 basic resource inventories upon which monitoring efforts can be based; (2) a network of 11 experimental or "prototype" long-term ecological monitoring programs begun in 1992 to evaluate alternative monitoring designs and strategies; and (3) implementation of operational monitoring of critical parameters (i.e. "vital signs") in approximately 270 parks with significant natural resources that have been grouped into 32 vital sign networks linked by geography and shared natural resource characteristics.

The network approach is designed to minimize redundancy, maximize cost effectiveness, and increase consistency in data collection and information transfer. The amount of funding available for vital signs monitoring would allow most parks to individually monitor only a few indicators. A key efficiency of the network approach is to identify and monitor a core set of ecosystem attributes and resource/stressor relationships that are important across a group of parks. In addition to increased efficiency, applying standard monitoring approaches across ecoregions will result in greater potential for comparison and explanation in the resulting datasets. NPS adopted the strategic approach of encouraging networks and parks to seek partnerships with federal, tribal, and state agencies and adjacent landowners to leverage monitoring funding. Ideally, network monitoring would form the middle tier of an integrated monitoring framework, linking national and regional monitoring programs to park-specific monitoring efforts.

1.2 ECOLOGICAL CONTEXT OF THE SOUTHERN PLAINS NETWORK

This section sets the scene for ecological monitoring in the Southern Plains ecosystem. The physical, natural, and cultural issues that are relevant to SOPN parks are discussed. The following sections describe the range of environmental conditions and anthropogenic influences

Table 1.2 Biophysical overview of the Southern Plains Network

Park	Annual Precip. (in.)	Avg. Min./Max Air Temperature (°F)	Elevation (ft)	Vegetation Province (Bailey 1994)
ALFL	20	43 / 71	2800 – 3320	Southwest Plateau and Plains Dry Steppe and Shrub
BEOL	12	37 / 69	3980 – 4020	Great Plains- Palouse Dry Steppe
CAVO	9	35 / 62	6990 – 8180	Great Plains- Palouse Dry Steppe
CHIC	38	49 / 72	780 – 1160	Prairie Parkland (Subtropical)
FOLS	23	41 / 67	2020 – 2095	Great Plains Steppe
FOUN	17	31 / 64	6685 – 6835	Southern Rocky Mountain Steppe-Open Woodland-Coniferous Forest-Alpine Meadow
LAMR	20	43 / 71	2800 – 3320	Southwest Plateau and Plains Dry Steppe and Shrub
LYJO	32	52 / 78	1190 – 1565	Southwest Plateau and Plains Dry Steppe and Shrub
PECO	17	32 / 63	6695 – 7575	Southern Rocky Mountain Steppe-Open Woodland-Coniferous Forest-Alpine Meadow
SAND	13	35 / 66	3940 – 4085	Great Plains- Palouse Dry Steppe
WABA	25	44 / 71	1920 – 2000	Great Plains Steppe and Shrub

prevalent in the Southern Plains Network region. More information about the SOPN natural resources can be found in detailed accounts of each SOPN unit (Appendix A), maps for the network and each park (Appendix E), as well as lists of species of concern (Appendix F), exotic plants (Appendix G), and exotic animals (Appendix H).

1.2.1 Setting the Boundaries

The SOPN consists of mostly mixed- and short-grass ecosystems and is bordered on the east by the tall-grass prairie and on the west by the forested systems of the Rocky Mountains. Parks within the SOPN vary in size from 326 acres (132 ha) to more than 46,000 acres (18,615 ha) (Table 1.1) and contain a wide range of biotic communities and abiotic conditions (Table 1.2). Most SOPN parks were established primarily for cultural and recreational reasons, and therefore have relatively few natural resource staff (Table 1.3). However all of the network parks contain significant natural resources. Many of these resources are imbedded within a framework focused on a human event or activity, and many parks enabling legislations have references to ecological systems such as maintaining the scene for the period of significance at a historical park. SOPN parks are some of the only representatives of short- and mixed-grass ecosystems in protected status. The parks are embedded in a landscape dominated by agriculture and act as natural oases that are refugia for endemic, threatened and endangered species, as well as common species.

Table 1.3 Natural Resource staffing in Southern Plains Network Parks.

Park	Job Title of the SOPN Technical Committee Member	Full-time Natural Resource Staff Positions
ALFL	None	None
BEOL	Chief of Natural Resources	Chief of Natural Resources
CAVO	Chief Park Ranger	None
CHIC	Chief of Resource Management	Chief of Resource Management
FOLS	Supervisory Park Ranger	None
FOUN	Supervisory Park Ranger	None
LAMR	Chief of Resource Management	Chief, Environmental Specialist
LYJO	Integrated Resources Program Manager	None
PECO	Park Ranger	None
SAND	Superintendent	None
WABA	Chief of Facilities and Resources	None

The SOPN currently has two full time staff and is overseen by a Technical Committee and a Board of Directors. The technical committee comprises of one representative from each park, generally the person who oversees natural resources, and the SOPN Network Coordinator. All are permanent members of the committee. The chair of the committee rotates on a two-year term between each park's member. The Board of Directors has both permanent and rotating members. There are three superintendents who each serve a three year term on a staggered rotation and the technical committee chair is a member during their two-year term. The Intermountain Regional Inventory and Monitoring Coordinator and the SOPN Network Coordinator are permanent members of the Board.

1.2.2 Individual Park Summaries

Alibates Flint Quarries National Monument

ALFL is 1,371 acres (555 ha) in size and adjacent to LAMR, was created in 1965 to preserve the extensive flint quarries that were once used as a source of raw materials for weapons and tools by prehistoric humans. ALFL also protects the ruins of several village sites of the Plains Village Indians that inhabited the area circa 1200 AD to 1450 AD. The Park remains undeveloped, therefore it is only open for guided tours. The landscape is rough and broken, having been cut by the Canadian River and its tributaries. The primary vegetative community at ALFL is mixed-grassland. The most serious concern for ALFL is erosion, which is affecting both the structural ruins and the terrain and is facilitating the invasion of non-native plant species.

Bent's Old Fort National Historic Site

BEOL covers 799 acres (323 ha) in Southeastern Colorado, along the Arkansas River. The original adobe fort was constructed in 1833 to serve as a trade center on the Santa Fe Trail. For much of the original fort's history it was the only major permanent white settlement on the Santa Fe Trail. In addition to supplying goods to the pioneers and the military, the fort became a staging area for the US Army during the Mexican War in 1846. The fort was abandoned in 1849 and was later established as a National Historic Site in 1960 by the NPS. BEOL falls within the Great Plains-Palouse Steppe and the short-grass prairie ecoregion (Bailey 1995). In addition to the Arkansas River, BEOL contains several wetlands and ponds. Maintaining the integrity of the riparian habitats, particularly the cottonwood/willow communities, is one of the highest concerns for BEOL Park managers. Native vegetation in the riparian habitats, as well as in other areas of the park, is being displaced by undesirable invasive species.

Capulin Volcano National Monument

CAVO was established to preserve the volcanic cinder cone that formed over 60,000 years ago. The Park covers 793 acres (321 ha) in Northeastern New Mexico. The primary vegetation types at CAVO are grasslands, which are growing upon thousands-of-years-old lava flow remnants, and piñon-juniper woodlands which may be encroaching upon the grasslands at the top of, and on the cone. One of the biggest concerns for CAVO is erosion of the cinder cone. The endemic Alberta arctic butterfly (*Oeneis alberta capulinensis*) is found at CAVO and only 5 other mountain tops in the region.

Chickasaw National Recreation Area

CHIC covers 9,889 acres (4,002 ha) in south-central Oklahoma. In the late 1800's the Chickasaw and Choctaw Native American tribal units recognized threats to the freshwater and mineral springs in this area and consequently requested that the federal government establish sustainable management practices (Wikle et al. 1998). This request ultimately led to the establishment of CHIC. Today, water-based recreation, such as fishing, boating, and water skiing are the largest attractions for visitors. CHIC lies within the Arbuckle Mountains geographic region and within the Red River drainage basin. Mixed grasslands and oak forests cover a large portion of the upland areas while riparian vegetation dominates the lowlands. The two largest bodies of water at CHIC are the Lake of the Arbuckles and Veteran's Lake. The most significant threats facing CHIC include such things as erosion along lakes and streams, exotic plant invasions, visitor effects on natural resources, water mining, and adjacent land use practices.

Fort Larned National Historical Site

FOLS encompasses 718 acres (291 ha) along the banks of the Pawnee River, most of which falls within the Pawnee River floodplain. Fort Larned, originally established to protect traffic along the Santa Fe Trail, became a key US military base during the period of Indian Wars. Prior to European settlement, the landscape at FOLS was covered with mixed-grass prairie and small wooded areas in the riparian areas of the Pawnee River. With agricultural development prairies were converted to croplands and woodlands were destroyed. The consequences of these changes are still a concern for Park managers today. Prairie restoration tops the list of management issues at this park.

Fort Union National Monument

FOUN, 721 acres (292 ha), was established in 1956 to preserve and protect the historic fort situated on the Santa Fe Trail in New Mexico. FOUN was originally constructed in the mid-19th Century as a military fort to guard the trail and supply other forts in the Southwest. Later, significant military campaigns were operated out of FOUN against Native American Tribes and in the Mexican and Civil Wars. The primary ecosystem present at FOUN is short-grass prairie. The two largest natural resource concerns for FOUN Park managers are invasive plant species and burrowing animals affecting the ruins.

Lake Meredith National Recreation Area

Lake Meredith was formed in the 1962 when the Bureau of Reclamation constructed the Sanford Dam on the Canadian River. It was designated as a National Recreation Area in 1990 and the ownership transferred from the BLM to the NPS. The lake was constructed to supply water to eleven surrounding communities, with recreational use of the area as a secondary purpose. The landscape at LAMR, covering 46,349 acres (18,757 ha) is characterized as rough and broken and can be divided into two distinct areas: the upland area including the mesa top with a steep, gravelly slope, and the bottomland area surrounding the reservoir.

Lyndon B. Johnson National Historical Park

LYJO preserves the birthplace, boyhood home, ranch, and final resting place of the 36th president of the United States as well as several other structures associated with the president and his ancestors. The two districts of LYJO, one consisting of the LBJ Ranch and the other consisting of the properties in Johnson City, Texas, total 674 acres (273 ha). LYJO lies in the "Hill Country" of south-central Texas and has a landscape of forested hills and grasslands. The Pedernales River, a tributary to the Colorado River flows through the Park. Several other small streams and ponds are also located within the Park boundaries. Erosion along stream banks and restoration of grasslands are the predominant concerns for LYJO.

Pecos National Historical Park

PECO, 6,670 acres (2,699 ha) was designated in 1965 to preserve an exceptional cultural and natural area that has had a long human history. Historically, the Pecos River Valley was a diverse area, with successive populations funneling through the valley. The Paleo-Indians, archaic people, basket makers, and Puebloan peoples all left evidence of early use and settlement in the valley. At Pecos, a fortress-like pueblo was established during the 15th Century and became a trading center for the region. The Spanish established a mission at Pecos in the late 16th Century. In the 19th Century, Pecos became a trading post and was later used for military expeditions during the Mexican war and American Civil War. In fact, the Battle of Glorieta that occurred at this site is considered one of the most important southwestern battles of the Civil War. Most of PECO lies in the upper Pecos River valley, bordered by the 13,000-foot Sangre de Cristo Mountains to the north, the rugged hills of the Tecolote Range to the east, and the steep Glorieta Mesa to the west. Glorieta Pass connects the Apache Canyon area and the northern Rio Grande Valley to the High Plains and short-grass prairie of New Mexico (Reed et al. 1999). Two of the largest natural resource management concerns are invasion of grasslands by piñon pine and exotic plant species.

Sand Creek Massacre National Historic Site

SAND is a 2,400 acre (971 ha) site that lies along a 5.5 mile (8.85 km) stretch of the Big Sandy Creek in southeastern Colorado. The landscape of SAND is largely mixed-grass prairies and wooded riparian areas. Trees on the site are eastern cottonwood, found in even-aged groves close to current or historic seasonal stream traces of Big Sandy Creek. SAND is within the High Plains section of the Great Plains-Palouse Dry Steppe Province ecoregion. SAND commemorates the Sand Creek Massacre that occurred in November 1864 when 700 U.S. volunteer soldiers were led into the area to attack and kill over 150 Cheyenne and Arapaho people, mainly women, children, and the elderly, who were peacefully encamped along Big Sandy Creek. SAND recognizes the significance of this massacre in American history, and its ongoing importance to the Cheyenne and Arapaho people and descendents of the massacre victims. The park's authorizing legislation directs NPS to manage the site as close as practicable to the 1864 cultural landscape.

Washita Battlefield National Historic Site

WABA is a 326 acre (132 ha) site located on the banks of the Washita River. This Park protects and interprets the site, at which the 7th U.S. Cavalry, led by Custer, attacked the Southern Cheyenne village of Chief Black Kettle in November, 1868. The site has cultural and historical value for the Cheyenne and other Southern Great Plains tribes; its protection supports their on-going struggle to maintain control of their traditional homelands (Milner 2003). The surrounding landscape is classified as dry plains, steppe with moderate valley slopes (2-20%) and a gently rolling topography (Bergey 2003). This site was drastically affected by the "Dust Bowl" in the 1930's (Inglis 2001), which caused changes to the local ecosystems, particularly soil health and water quality/quantity. Restoring natural conditions of the environment is the primary concern of land managers at WABA.

1.2.3 Vegetation

The SOPN is located primarily in the grassland or Great Plains biome, considered by some to be the largest biome in North America (Stubbendieck 1988) and is among the most productive ecosystems on earth (Williams and Diebel 1996). However, the North American Prairie is also among the continent's most endangered resources (Samson and

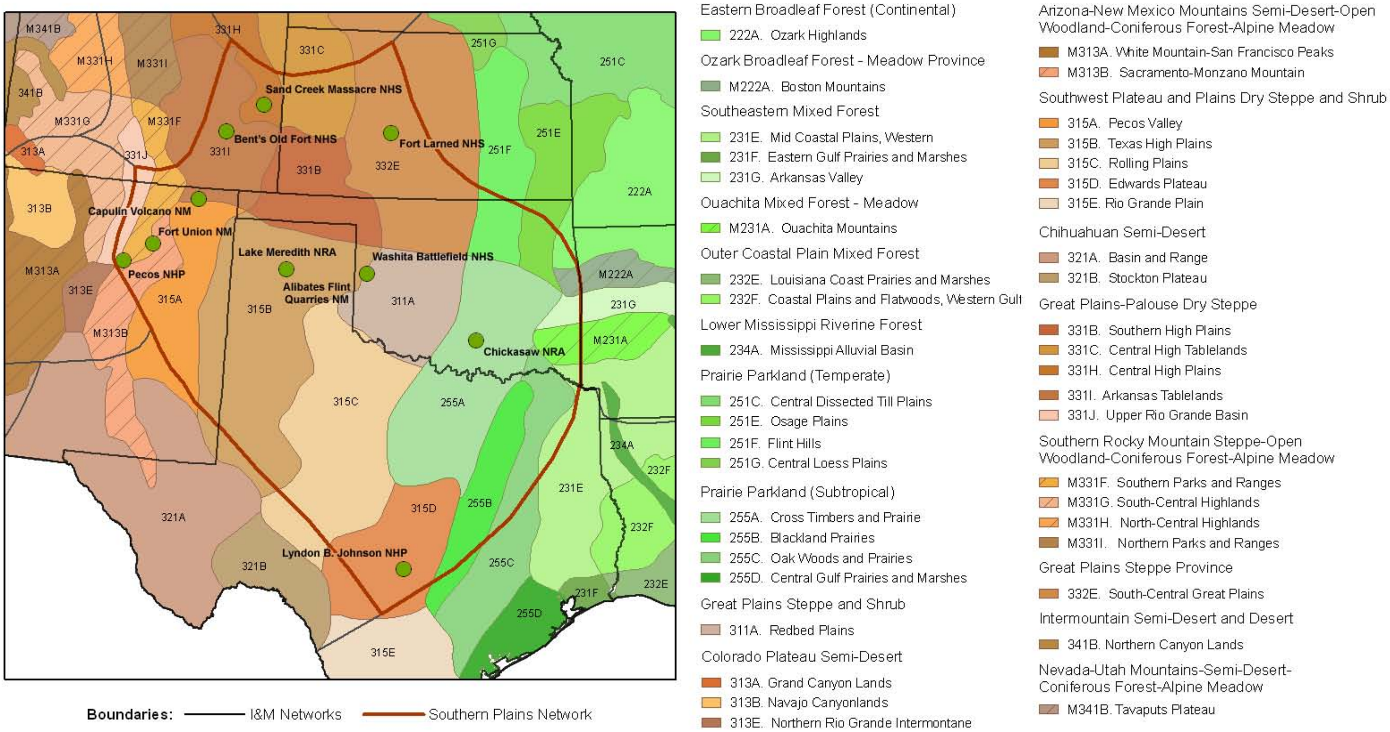

Figure 1.3 Bailey's Ecoregion (1995) section map for the Southern Plains Network

Knopf 1994, Rickletts et al. 1999). Most ecologists divide the Great Plains into three types, which actually represent a gradient starting with tall-grass prairie on the eastern plains, mixed-grass prairie in the central regions and short-grass prairie in the west. Fort Union NM, Capulin Volcano NM, Bent's Old Fort NHS, Lake Meredith NRA, Alibates Flint Quarries NM, and Sand Creek Massacre NHS are located in short-grass prairie, while Fort Larned NHS, Washita Battlefield NHS, Chickasaw NRA, and Lyndon B. Johnson NHP are in mixed-grass prairie or savannah, and Pecos NHP is in the ecotone between short-grass prairie and piñon-Juniper forest. At a finer scale the 11 parks in the Network can be placed in 6 different vegetative zones or biomes (Küchler 1986, Omernik 1987, Bailey 1995) (Table 1.2) and 8 vegetative sections (Figure 1.3).

The dominant native plant species in the western portion of the network are blue grama (*Bouteloua gracilis*) and buffalograss (*Buchloe dactyloides*) in the grasslands, and cottonwood (*Populus deltoides*) trees along the riparian areas. In the eastern portion of the network big and little bluestem (*Schizachyrium scoparium*), switch grass (*Panicum virgatum*), and Indian grass (*Sorghastrum nutans*) become more dominant in the grasslands, and American elm (*Ulmus americana*), sugarberry (*Celtis laevigata*) bald cypress (*Taxodium distichum*) and green ash (*Fraxinus pennslyvanica*) trees are added along with cottonwoods in riparian areas.

Due to alterations in natural fire and grazing cycles many of the grasslands are being invaded by woody species, such as oneseed juniper (*Juniperus monosperma*). Exotic plant species such as smooth brome (*Bromus inermis*), cheatgrass (*Bromus tectorum*), Kochia (*Kochia scoparia*), and King Ranch bluestem (*Bothriochloa ischaemum*) have invaded the grasslands and tamarisk (*Tamarix spp.*), scotch thistle (*Onopordum acanthium*), and Russian olive (*Elaeagnus angustifolia*) threaten riparian areas.

Species diversity is high in the mixed-grass prairie areas with hundreds of plant species typically found per square mile. For example, Sanders and Gallyoun (2004) and Sanders (2005) found 471 naturally occurring species at Lyndon B. Johnson NHP and Hoagland and Johnson (2001) found 582 species at Chickasaw NRA during plant inventory work. Interestingly, despite high diversity, endemic plant species are rare in the Great Plains when compared to many other biomes. However, there are a few endemic species that are found or are likely present in SOPN, such as Colorado bursage (*Ambrosia linearis*) and dwarf milkweed (*Asclepias uncialis*). Many of the dominant forbs are polycarpic (flower and set seed many times) and have long life spans of 10 to 30 years (Blake 1935, Weaver 1954). Most reproduction of prairie perennials is accomplished via vegetative reproduction, with regeneration from seeds playing a minor role (Weaver and Mueler 1942, Tripathi and Harper 1973, Glenn-Lewin et al. 1990). After moisture, successful colonization of the seedling routes by micorrhizal fungi is likely the most important condition for seedling establishment (Hartnett and Keeler 1995). Despite large numbers of seeds, successful seedling establishment is a rare event that only occurs when a seed reaches an appropriate micro-site for germination and encounters the required favorable conditions after germination. Small patches of disturbance create openings for opportunistic short-lived species. These species are generally forbs and are ephemeral in nature, colonizing the site when there are disturbances and gradually declining as the dominant species move in.

The number of dormant seeds in the soil far exceeds the number of above ground established plants. These buried seeds have their own community with additions arriving from aboveground seed production and losses resulting from germination, predation, fungal decay, and migration via faunal transportation. The dominant perennial grasses and forbs generally do not maintain large or persistent soil seed banks (Blake 1935, Lippert and Hopkins 1950, Rabinowitz 1981), while the less-common, short lived species have seeds that can remain viable in the soil for decades (Rice 1989). For example, seed banks in Colorado short-grass prairie are dominated by early successional annuals and show poor correlation between relative population abundances above ground and relative abundances in the seed bank (Coffin and Lauenroth 1989).

The Great Plains grasslands evolved relatively recently (Axelrod 1985). This area was likely woodlands during the early Miocene. Increasing aridity in the Miocene and Pliocene resulted in forests being restricted to moister valleys and relict forests. The increased aridity favored grasses and increased drought resulted in conditions favorable to fire which could spread quickly over the flat and gently rolling terrain when combined with southerly and westerly winds. The rise of grasslands likely began in the Miocene-Pliocene transition (7-5 million years ago) but some areas of the Great Plains were still covered with trees as recently as 15,000 to 12,000 years before present (Axelrod 1985). The increase in fires gradually destroyed relict forests and prevented them from regrowing, but this did not eliminate grasses due to their growth occurring at or below the soil surface. The idea that the Great Plains grasslands are relatively young is supported by fossil floras, relatively low rates of endemism, and relict occurrence of diverse trees over the region and invasion of grasslands by woody vegetation (Axelrod 1985). The occurrence of trees along escarpments and their invasion of grasslands demonstrate that the lack of trees in the Great Plains is not due solely to low precipitation, but rather the interaction of climate and fire.

Grasses have the unique ability to thrive without a canopy and with major disturbance processes such as drought, fire and grazing. Unlike most plants that add new growth to their tips, grasses grow from their base and have an extensive root system. In this fashion the sensitive growth tissues can remain below the soil protected from grazing, fire, and drought. The extensive root system allows for regrowth after disturbances and can extend 10-15 feet (4.5-6 m) below the surface which gives grasses the ability to extract moisture deep below ground during time of drought. While grasses dominate the Great Plains in terms of biomass, about 3 of every 4 species present are forbs. Many forbs send their roots even deeper then grasses to tap into water that is out of reach for grasses. Many forbs also bloom early in the spring in order to capture the early season resources before grasses.

Many grassland systems have undergone significant changes since they were first described by early Europeans. Exotic species invasions, expanding row-crop agriculture, overgrazing, mineral exploration and establishment of woodlots and shelterbelts have all contributed to grassland degradation and significant and ongoing loss of genetic diversity in North American grasslands. Estimates for loss of mixed-grass prairie range from 30-99.9% and for short-grass from 46-82% depending on the region (Samson et al. 1998). Prairie restoration is receiving increased attention in the Great Plains because many grasslands have been converted to other uses. Several SOPN parks have completed, or are in the planning process for restoring prairie. Unfortunately, this can be a long process if the soil has been tilled. Fuhlendorf et al. (2002) estimates that it may take restored sites 30-50 years to recover and may require inputs to restore organic matter, soil carbon, and soil nitrogen.

1.2.4 Fauna

The Great Plains historically supported a wildlife community that was similar in structure, processes, and behavior to grassland wildlife assemblages throughout the world (Knopf and Samson 1997). In the mid-1800's the numbers of individuals of native mammal species such as bison (*Bison bison*), black-tailed prairie dogs (*Cynomys ludovicianus*), pronghorn (*Antilocapra americana*), elk (*Cervus elaphus*), grizzly bears (*Ursus arctos horribilus*), and gray wolves (*Canus lupus*) rivaled or exceeded those now in the African Serengeti (Howe 1994), occurring in unfathomable numbers. Estimates of bison may have been as high as 60 million (Knopf and Samson 1997) and there were between 40 to 100 million ha of prairie dog towns in 1900 (Miller et al. 1994).

The decline of bison and prairie dogs from their historic levels are particularly important when understanding current grassland dynamics. Grazing by bison and prairie dogs was a primary driver of the ecology in the Great Plains and the two species are often viewed as mutualistic. Bison and other large herbivores such as elk and pronghorn use prairie dog colonies for grazing and loafing, on a greater basis then would be expected based on the habitat available, due to the higher nutritional value of plants within dog towns (Koford 1958, McHugh 1958, Coppock et al 1983a, Krueger 1986). After bison herds graze an area and move on, a mosaic of seral stages is created across the landscape (Hart and Hart 1997). This high intensity, low frequency grazing probably had a profound impact on major grassland processes. This grazing regime would affect everything from the types of vegetation communities present to stopping major fires due to being overgrazed, or even overtrampled (when bison were trying to escape the fire) areas. Bison "so completely consumed the herbage of the plains that detachments of the United States Army found it difficult to find sufficient grass for their mules and horses" (Hornaday 1889).

Prairie dogs have additional roles in grassland systems. The presence of a colony increases the chances that other rare species such as mountain plovers (*Charadrius montanus*) (Knowles et al. 1982, Knopf 1996), ferruginous hawks (*Buteo regalis*) (Cook et al. 2003), burrowing owls (*Athene cunicularia*) (Desmond et al. 1995) and swift foxes (*Vulpes velox*) (Agnew et al. 1986) will be present. Their tunnel system also provides refuge for a variety of taxa ranging from invertebrates to amphibians and reptiles. The prairie dogs also play an important role in nutrient and soil cycling and as prey species for higher trophic levels.

Lark sparrow at Lake Meredith NRA

There are relatively few endemic vertebrates in the Great Plains, perhaps due to the relatively young age of the ecosystem (Axelrod 1985). The endemics that do occur generally evolved in the drier, westerly plains (Knopf 1996, Knopf and Samson 1997). The Rocky Mountain locust (*Melanopus spretus*) was a Great Plains endemic that is now thought to be extinct (Lockwood 2004). This species would periodically irrupt and migrate in great swarms that would significantly alter the ecosystem in some years and have little to no effect in other years. It has not been seen since the 1920's and is believed to have been eliminated as a result of land-use changes in the high plains of Colorado and Wyoming (Costello 1969, Joern and Gaines 1990).

The absence of large carnivore species, particularly the gray wolf, has also changed the Great Plains animal communities. The absence of the wolf has allowed coyotes to expand and flourish as well as other meso-carnivores at the expense of grassland birds, small mammals and two other rare prairie predators: the swift fox and black-footed ferret (*Mustella nigripes*). Other predators that inhabited the prairie and have declined or been extirpated include mountain lions (*Puma concolor*), grizzly bears, black bears (*Ursus americana*), fishers (*Martes pennanti*), lynx (*Lynx canadensis*), and river otters (*Lutra canadensis*). The Great Plains has lost a greater number of native carnivores and ungulates than any other biome in North America (Laliberte and Ripple 2004).

The Great Plains historically had high levels of faunal biomass, however, it does not have high species richness. Birds, reptiles, and amphibians all have low species richness, when compared to other North American ecosystems. The species present have had to adapt to the highly variable weather patterns. This specialization and low species richness make Great Plains wildlife especially vulnerable to habitat alteration. For example, the grassland bird guild has been found to have suffered steeper declines than any other North American bird guild (Knopf and Samson 1996, Peterjohn and Sauer 1999, Brennan and Kuvelsky 2005). Knopf and Samson (1996) argue that the endemic vertebrates of the Great Plains are the most sensitive to changes in ecological drivers of the region and therefore should be considered indicators of ecosystem health.

Habitat degradation of prairie has led to the region wide decline of several rare and listed species including four that are known to occur in SOPN parks, the burrowing owl, black-tailed prairie dog, mountain plover, and Texas horned lizard (*Phrynosoma cornutum*), and three more that may occur on some of these parks, the lesser prairie chicken (*Tympanuchus pallidicnctus*), Arkansas darter (*Etheostoma cragini*), and swift fox. Federally-listed species that occur in the region include the Arkansas River shiner (*Notropis girardi*) and the wintering bald eagles (*Haliaeetus leucocephalus*) at Lake Meredith NRA, migrating eagles at several parks, and black-tailed prairie dogs (candidate) at Bent's Old Fort NHS, Sand Creek Massacre NHS, Fort

Larned NHS, and Lake Meredith NRA. Additional species of concern are listed in Appendix F.

Fragmentation is perhaps the greatest threat to faunal communities and has had three effects on grassland fauna. First, many species require large areas for survival and reproduction (Samson 1980, Herkert 1994). Second, as fragments become more isolated, the probability of being recolonized diminishes (Kaufman and Kaufman 1997). Lastly, the combination of small size and isolation can lead populations to suffer from genetic inbreeding and increased rates of genetic drift (Benedict et al. 1996). Species that are less vagile can quickly be isolated to relict populations.

1.2.5 Processes

Fire, grazing, and climate, specifically drought, are the major natural drivers of Great Plains ecosystems. Grazing and fire have generally operated at landscape and local scales, with drought at a broader scale (Fuhlendorf and Engle 2001). The absence or alteration of the first two drivers has had significant impacts on the grassland community. Both grazing and fire have been absent or reduced in many SOPN parks, in some cases for decades. In addition these drivers are no longer functioning at the landscape scale as they did in pre-Columbian times due to the small size of parks, ownership fragmentation, and land conversion. Therefore, restoring plant community heterogeneity that was previously present is difficult and can only be done at a drastically reduced scale. The agrarian-dominated landscape, the small size of the parks, and the scale at which ecological processes naturally occurred in the region, all affect park management. None of the SOPN parks are large enough to restore and maintain complete assemblages of native species, natural conditions on a pre-European scale, nor the ecological processes that sustained them. However, due to the rarity of high-quality short-grass and mixed-grass prairie, it is essential that prairie in NPS ownership be maintained in optimal condition to provide habitat for rare species, facilitate important nutrient cycling, and serve as an example of grassland fragment management. The development of a long-term monitoring plan must consider these aspects in design and implementation. Adequate assessment and monitoring of the effects of grazing, climate, and fire on grasslands, must be multi-scaled, include spatial and temporal patterns, and match management inferences and applications (Steinauer and Collins 1996).

Fire

Climate and fire are the biggest determinants of whether grasslands preclude forests in the Great Plains region (Axelrod 1985, Anderson 1990). Fire can interact with drought by affecting the amount of fuel available, the influence of precipitation on prairie post-burn, and the moisture content of the vegetation can determine where fires are possible (Anderson 1990). The interaction of fire with grazing has a profound effect on the composition, structure, and processes of Great Plains plant communities. For example, pocket gophers and fire may be required to maintain the endemic perennial forb (*Penstemon grandifloris*) that is found in sandy prairies (Davis et al. 1991a, 1991b). Without fire, many areas, particularly in the eastern part of SOPN, would succeed to shrublands or forests (Sauer 1950). Fire-induced mortality of woody plants is tied to their morphology and life-history traits (timing of above-ground growth, translocation of carbohydrate reserves, unprotected aboveground meristems). Grasses can die down so that only underground portions are maintained with dead tops above the surface. This adaptation helps them survive fire as well as drought. Growing points beneath the surface allow the plants to regrow after fire and grazing have removed the above ground tissues. Productivity of grasslands is generally enhanced by the removal of excess biomass (dead tops) through grazing or periodic fires (McNaughton 1979, Risser et al. 1981, Anderson 1982, Dyer et al. 1982, Knapp and Seastedt 1986).

Prescribed fire at Lyndon B. Johnson NHP

Fire frequency and seasonality plays a large role in the ecology of the Great Plains. Frequent fire is essential to maintaining native species diversity, and it affects other components, including nutrient cycling and productivity (Collins and Wallace 1990). Historically, lightning and Native Americans were the principal causes of fire. SOPN parks generally average between 40 and 50 days with thunderstorms per year (Bryson and Hare 1974) and fire ignited by summer storms occurred May through September (75% of these between July and August) when storms are most common (Bryson and Hare 1974). In the southern mixed-grass prairie, Native Americans appeared

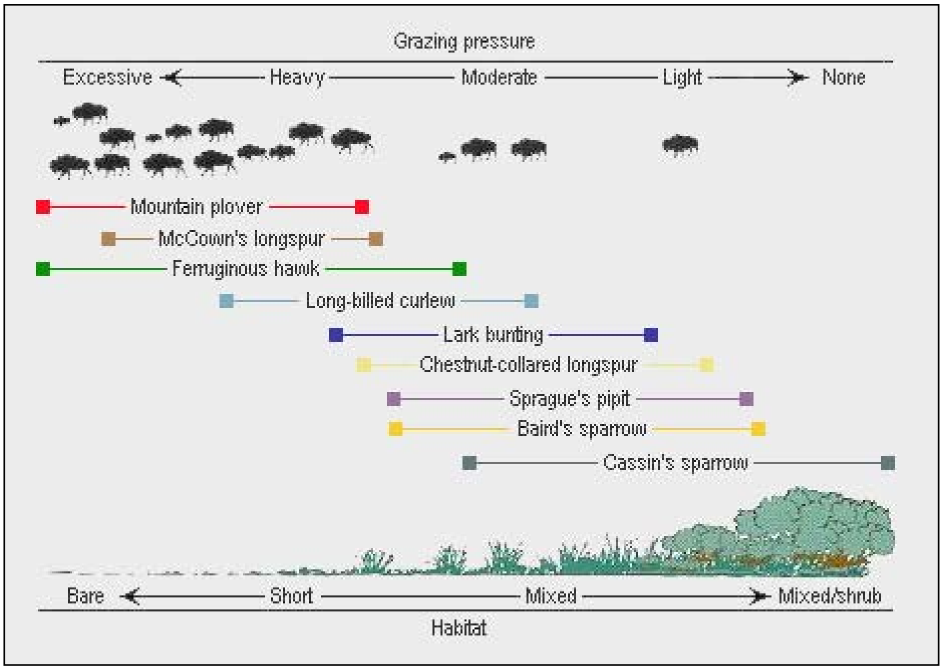

Figure 1.4 Distributions of endemic birds of prairie uplands on a short/mixed-grass and historical grazing continua across the western Great Plains (From Knopf 1996).

to use fire most frequently in July and August (Moore 1972). The southern mixed-grass prairie has slow litter accumulation and fires probably occurred every 3 to 10 years (Umbanhowar 1996) due to slow litter accumulation. Lewis and Clark found the mixed-grass prairie "much parched with frequent fires" (Lewis 1961:66). In short-grass, fires were less frequent, although they were reported from early travelers and were still an ecological driver of the system (Brockway et al. 2002). Large mammals, such as pronghorn, elk, bison, and rabbits concentrated on burned areas (Lewis 1973, Evans and Probasco 1977) and burning was used by Native Americans for hunting (Moore 1972).

Fires can burn extensive areas in the Great Plains due to the combination of flat and rolling terrain with winds from the south and west. Natural fire breaks would have existed only along streams in the form of gallery forests (Abrams 1986) and in areas that recently had been heavily grazed by bison. Pre-European fires were much larger then the prescribed fires and wild fires that occur today. There is record of a fire in 1885 that started in western Kansas, jumped the Cimarron River, and burned across the north plains of Texas, a distance of 175 miles (282 km) (Haley 1929). This fire may have been unprecedented in size, but historical accounts of nineteenth century immigrants clearly identify the significance of frequent, large fires (Mattes 1969).

Today, increased livestock grazing keeps fuel loads lower which reduces fire intensity across the Great Plains and eliminates it entirely in portions of the short-grass prairie. Prescribed fires are small and controlled, generally conducted on days when the fire is most easily contained. Many SOPN parks have not had prescribed fire for decades and are just recently considering prescribed fire and developing fire management plans.

Grazing

Grazing is still a dominant process in the Great Plains, but the timing, intensity, species, and duration have all changed substantially. Grazing has direct and indirect effects at landscape and regional scales, which, in turn, interact with other small-scale and large-scale factors to heighten temporal and spatial diversity in grasslands (Gibson and Hulbert 1987; Risser 1990). Historically fire and grazing interacted through a series of positive and negative feedbacks that resulted in a shifting mosaic of vegetation patterns across the landscape (Hobbs et al. 1991, Fuhlendorf and Engle 2001, 2004). The probability of fire is greatest on areas with high biomass accumulation within a grazed landscape, a result of low grazing pressure. Grazing animals in turn are attracted to the most recently burned areas (Coppedge et al. 1998, Coppedge and Shaw 1998). Through grazing, biomass is reduced, more bare ground is present, and the probability of fire is reduced. Lack of fire leads to reduced grazing, the grass then recovers and becomes more susceptible to burning. This patchy landscape had a profound effect on other vertebrate fauna. For example, grassland birds occupy a wide range of grasslands from heavily grazed to ungrazed (Knopf 1996) (Figure 1.4). Grazing is not limited to ungulates, as black-tailed prairie dogs can have a major effect, particularly in short-grass systems. A positive feedback between prairie dogs and other grazers resulted in increased use of these areas by bison and pronghorn (Coppock et al. 1983b, Coppock and Detling 1986, Krueger 1986).

Grasslands in the Great Plains have evolved with grazing. Nodal rooting, or underground branching, thorns and spikes, secondary compounds that are difficult to digest and unpalatability are evolutionary responses of the long co-evolutionary association between plants and grazing animals. However, different levels of grazing can have dramatically different effects. Under certain conditions grazing can increase species diversity (Bakker and Ruyter 1981). In the short-grass prairie, moderate levels of grazing can stimulate growth of dominant grasses with rapid growth that helps them to maintain a competitive edge over invading grasses and forbs (Risser 1990). Grazing of little bluestem in Texas can result in fragmentation of clones (clumps), decreasing their mean size but increasing the total density of clumps in an area (Butler and Briske 1988). Within the clumps, grazing can increase tilling, extend the season of tiller recruitment, and increase the number of tillers per unit area (Butler and Briske 1988). Heavy grazing can change the plant community and can lead to losses of pollinators and seed dispersers and fossorial animals that aerate the soil and are involved in nutrient cycling (Stafford Smith and Morton 1990, Yeaton and Esler 1990). Overgrazing can increase water runoff and erosion by reducing infiltration of water (Fuls 1992, Thurow et al. 1988) in part due to a reduction in soil-dwelling insects that aerate the soils (Whitford 1986). This reduction in water conservation leads to reduced grassland productivity and in extreme cases can contribute to desertification of these landscapes (Schlesinger et al. 1990).

Grazing and drought can combine to affect heterogeneity in plant composition. In the short-grass prairie, blue grama and buffalo grass are the dominant grasses. Both are C_4 species with similarphenology and can withstand heavy grazing. Blue grama is thought to be able to better withstand drought (Albertson and Tomanek 1965), but buffalo grass increases in abundance under heavy grazing (Savage and Jacobson 1935) and has higher photosynthetic rates at low temperatures (Monson et al. 1983).

Bison were the dominant grazer during pre-European times. Bison graze grasses over other plants (Peden et al. 1974, Meagher 1978, Shwartz and Ellis 1981, Plumb and Dodd 1993, Steuter et al. 1995) which results in a heterogeneous landscape with distinct grazed patches that alters the competitive relationships among plants (Fahnestock and Knapp 1993, 1994, Catchpole 1996). In 1845, Fremont wrote that bison 'scarcely left a blade of grass standing' (White and Lewis 1967:320). Bison and ungulates can dramatically alter nutrient cycling (Frank et al. 1994, Frank and Evans 1997), and grazing can stimulate nutrient uptake and increase N concentrations (Coppock et al. 1983b, Jaramillo and Detling 1988, Green and Detling 2000). In addition ungulates can increase rates of denitrification (Groffman et al 1993), ammonia volatilization (Schimel et al. 1986, Frank and Zhang 1997), net N mineralization (Holland and Detling 1990) and nutrient redistribution through urine and fecal deposition (Day and Detling 1990, Frank and Evans 1997). Bison have been shown to increase aboveground productivity (Frank and McNaughton 1993), rates of nutrient cycling (Day and Detling 1990, Frank and Evans 1997, Knapp et al.1999) and the spatial heterogeneity and relative abundance of certain plant species (Coppedge et al. 1998, Knapp et al. 1999).

Prairie dogs were also a dominant grazer but were more sedentary than bison. Prairie dogs can affect the graminoid biomass and ratio of grasses to forbs (Cid et al. 1991), reduce biomass of roots while increasing density of nematodes (Polley and Detling 1988, 1990, Whicker and Detling 1988). Grazed plants in prairie dog towns have higher nutritive value than uncolonized grassland (Kaufmann and Kaufmann 1997), which subsequently led to increased grazing in prairie dog towns by large herbivores. Uresk and Paulson (1988) estimated that 300 prairie dogs consume about the same amount of vegetation as a cow-calf pair. Prairie dogs have been eradicated from large portions of their range in the name of ranching interests. However, market weights of steers have not been found to be affected by the presence of prairie dog towns (Hansen and Gold 1977, O'Meilia et al. 1982).

Below ground processes have also evolved with grazing. Soil dwelling herbivores and detritivores often increase under moderate grazing, but decline under heavy grazing (Seastedt et al. 1988). The plains pocket gopher (*Geomys bursarius*) is another important vertebrate due to its burrowing and mounding activities which alter essential plant resources. Root herbivory occurs underground and the deposition of subsurface soil in mounds aboveground buries plants and alters light, water, and nutrients. Mounds are strongly clumped in a uniform pattern which influences the adjacent plant community. Plant growth is inhibited over the disturbance, and an increase in resources and plant growth adjacent to the disturbance results in a competition-induced wave of biomass emanating out at least 20 inches (50 cm) from the disturbed site (Reichman et al. 1993).

Modern range practices with livestock generally do not produce the landscape heterogeneity produced by historic grazing patterns (Hart and Hart 1997). Grazing practices are focused on uniform disturbance through uniform distribution of grazing animals on temporal and spatial scales. Modern grazing practices can transform grasslands into shrub-dominated states that cannot be returned to grassland by changes in grazing management alone (Westoby et al. 1989, Laycock 1991, Milchunas and Lauenroth 1993, Stringham et al. 2003). Overgrazing reduces fuel levels which can lead to tree and shrub expansion (Humphrey 1958, Archer et al. 1988). Livestock present for prolonged durations focus on the most palatable species and can eventually eliminate them from the seed bank. Overgrazing can produce a shift from grasses to plant assemblages dominated by toxic and spinescent woody plants (Westoby et al. 1989). These unpalatable woody species (honey mesquite [*Prosopis glandulosa*], oneseed juniper, ashe juniper) and cactus species (*Oppunitia spp.*) increase and can become the dominant cover. As the plant community changes, some ranchers make use of livestock that can feed on a wider and wider spectrum of plants, exacerbating the effects. Cows also tend to congregate in riparian areas more then bison, which can lead to degradation of the entire ecosystem (Martin and Ward 1970, Foran and Bastin 1984, Fuls 1992, Watkinson and Ormerod 2001, Landsberg et al. 2003, Tobler et al. 2003). Historic grazing by bison would have been high intensity, low frequency grazing that would have given most species a chance to recover during long rest periods.

Future grazing practices should focus on not only restoring late successional stages, but also on restoring the heterogeneity within the landscape (Hartnett et al. 1996, Coppedge et al. 1998, Fuhlendorf and Engle 2001). Discrete fires and patch selective grazing can have the result of a shifting mosaic across the landscape. Small NPS park units in particular, need to consider not only their own management, but also the land management on surrounding areas when determining their place in a heterogeneous landscape. In order to restore short-grass and western mixed-grass prairie, range managers need to move towards non-traditional range management practices that re-examine the traditional tools and practices (Samson et al. 2004). Grazing has primarily been accomplished through fencing which enables management agencies to establish standardized guidelines for removal of grazers from ecosystems. As fencing increases, the heterogeneity decreases and the probability for a suite of viable species, such as grassland birds, decreases. Standard management practices preclude endemic species that exist at the ends of the grazing gradients (Knopf 1994).

Climate

The Great Plains climate is typified by highly variable and stormy weather patterns and increasing precipitation from west to east across the plains (Parton et al. 1981, Risser et al. 1981). Climatic extremes like drought have affected animal and plant abundances for centuries. Bison have been documented to die by the thousands in sustained droughts (Roe 1951) and severe winters can kill pronghorn. Drought can affect some grazing species in the year of the drought, while having a lag effect of a year or more on fauna that feed on seeds like small mammals (French et al. 1976). Precipitation, evapotranspiration, temperature, and fire all combine to define the boundary where tree growth is possible. These conditions result in a line along the eastern edge of the tall-grass prairie which largely prohibits tree growth through much of the Great Plains and SOPN. Climate and fire are thought to be most important processes to the spread and maintenance of grasslands (Anderson 1990).

Storm approaching at Pecos NHP

Great Plains weather is highly influenced by the clashing of air masses from westerly winds that are modified by arctic airstreams from the north and tropical airstreams from the south. This mixing produces results in variable weather, particularly in the summer. Westerly air masses that become saturated over the Pacific Ocean have been obstructed by the Rocky Mountains which causes precipitation over the mountains and drier conditions on the leeward side of the mountains. These drier conditions result in the short-grass ecosystem of the western plains. As these air masses continue across the broad flat plain they increase in temperature and can hold more moisture. These westerly winds can then collide with arctic and tropical masses and result in stormy, unstable climatic summer weather conditions. The clashing of air masses provides more rainfall which supports the mixed-grass of the central Great Plains, and still more rainfall for the tall-grass prairie of the eastern plains. Annual precipitation within SOPN ranges from 12 inches (31 cm) in the western plains to 39 inches (97 cm) in south central Oklahoma. Approximately 2/3 of this rainfall occurs from April through September.

There is a general temperature gradient in the Great Plains increasing from northwest to southeast. In SOPN parks the average maximum daily temperature ranges from 78°F (26°C) at Lyndon B. Johnson NHP to 62°F (17°C) at Capulin NM, with average minimum temperatures ranging from 52° F (11°C) at Lyndon B. Johnson NHP to 31° F (-0.5°C) at Fort Union NM (Table 1.2). This change in temperature results in a north-south gradient between cool-season (C_3) grasses and warm-season (C_4) grasses. Cool season grasses are most efficient photosynthesizing in cooler temperatures and dominate in the northern or higher elevation plains, where warm-season grasses are more efficient under warmer temperatures (Black 1971) and are more dominant in the grasslands that make up SOPN.

In addition to seasonal variation, Great Plains weather patterns are also highly variable from year to year, decade to decade. The inherent unpredictability of precipitation across years had influence on the evolutionary processes of the Great Plains (Mock 1991). Drought can lead to massive local extinctions of annual forbs and grasses that have invaded stands of perennial species, and recolonization can be slow (Tilman and El Haddi 1992). The Great Plains, particularly the short-grass prairie and the southern mixed-grass that make up SOPN, undergo frequent droughts from reduced precipitation, increased evapotranspiration, and increased water runoff (Weaver 1968, Wilhite and Hoffman 1979). Multi-year droughts on a cycle that has ranged from 10-20 years over the past few centuries (however, pre-Columbian cycles may have lasted much longer; Clark et al. 2002) are a regular event. Organisms that live in this area must be adapted to surviving these periods of drought and increased stress. Drought can significantly affect the plant community, reducing vegetative cover, changing species composition, lowering flowering rates, and increasing wilted conditions. These droughts are really "normal" events and many of the more common plants, such as sideoats grama (*Bouteloua curtipendula*), blue grama, buffalo grass, and western wheat grass (*Agropyron smithii*), in SOPN are better adapted to persisting in droughts and in some cases take advantage of drought conditions (Weaver 1954).

The impact of global climate change may be exacerbated in the Southern Plains due to the region's periodic droughts and the large number of habitat specialists (e.g. prairie dogs and associated species) (Collins and Glenn 1995, Clark et al. 2002). Once these communities are isolated as 'islands' such as those represented by the SOPN, species extirpations may occur due to the inability to re-colonize. Changes to weather patterns, especially outside the normal range of variability, can have significant impact on grassland vegetation (Clark et al. 2002). In Weaver's (1943) classic vegetation study during and after the Dust Bowl of the 1930s he found that the mixed-grass prairie biome had moved a hundred miles to the east.

The unique weather patterns of the Great Plains present some challenges when designing a long-term monitoring program. The inter-year variability can increase the noise to signal ratio in monitoring projects. This can confound efforts to analyze and interpret temporal and spatial trends and to identify causative factors in changes in natural resources. In addition, there can be large local variation in precipitation, necessitating site-specific weather monitoring stations to obtain accurate information.

1.2.6 Soils and Geology

Prairie soils were formed primarily from sediment washed down from the Rocky Mountains, mixed with rubble from glaciers, and windblown sand, silt and clay. This combination results in a nutrient-rich, deep soil that is some of the most productive on earth. Grassland soils are fundamentally different then forest soils (Simms 1988). Forested areas generally contain 20-50 tons of topsoil per acre, while an acre of tall-grass prairie can contain as much as 250 tons per acre. The SOPN has a wide range of soil orders present, including dry mollisols through central Texas, central Oklahoma and central Kansas, wet mollisols in the vicinity of Chickasaw NRA, entisols and aridisols in southeastern Colorado and aridisols and alfisols in northeastern New Mexico. These soils are deep and loamy on the eastern part of the plains and shallow and hard in the west. Soil formation is a slow, continuous process. About 1 inch (2.5 cm) of new topsoil is formed every 100 to 1,000 years, depending on climate, vegetation and other living organisms, topography, and the nature of the soil's parent material (Sampson 1981). Prairie soils are generally nitrogen and carbon poor, although there is wide variability. Soil nutrient transport is generally slow; however, fire and grazing (especially under historic patterns) can cause rapid pulses of transport. Where evaporation is low, water is more likely to remain in the soil, increasing the rate of mineral weathering and allowing large amounts of nitrogen, phosphorus, and sulfur to accumulate in conjunction with carbon.

Much of the biotic community and biomass of prairie exists below the surface. Roughly 85% of a prairie's vegetative biomass can be below ground (Sims and Singh 1971). A square yard of soil just 4 inches (10 cm) deep may contain roots that would stretch for 20 miles (32 km) if they were placed end to end and may contain over 110,000 arthropods and 5.4 million nematodes (Risser et al. 1981). In short-grass prairie soils, 90% of invertebrate energy cycling occurs belowground, less in tall-grass and mixed-grass prairies. Earthworms accelerate the decomposition and mineralization of soil organic matter and affect soil structure through burrowing and casting. In some areas the soil formation activities of earthworms are being affected by the introductions of non-indigenous species (James 1991). In addition, many of the vertebrate species are fossorial, including prairie dogs, a keystone species in the system.

The extensive root system makes original prairie sod a great conserver of soil and water. The deep roots of the grasses and forbs act like a sponge to catch and hold rainwater. Water runoff from prairie is relatively small when compared to row crops or other ecosystems where there is no large network of roots. The extensive root system also binds the soil to the earth, protecting it from erosion. Prairie sod is so dense that settlers once used it like bricks to build houses.

As Europeans moved west, native prairie began to be converted to cultivated agriculture as early as the 1850's (Peterson and Cole 1996). When prairie is converted to row crop agriculture, the mixing and grinding of farm tools reduces surface cover and destabilizes soil structure by reducing aggregate size. In addition, organic carbon loss is accelerated by agriculture, and cultivated crops return little carbon to the soil. The early farming practices did very little to capture and retain moisture. The Dust Bowl of the 1930's, centered on the Southern Plains, was a result of removing the protective vegetative layer and exposing vast areas of cultivated prairie soil to wind action and drought (Sampson 1981). In addition, chronic heavy grazing by livestock can compact soils and affect many of their characteristics and functions (e.g., water infiltration). Several SOPN parks contain tracts of formerly cultivated land that are in various stages of restoration.

There are several relationships that exist between plant productivity and soil organic material that occur after native sod is converted to row-crops. First, soil productivity decreases dramatically. Williams and Wolman (1986) found that soil productivity (indexed by corn grain yield) declined 71% and soil nitrogen 49% during a 28-year interval after cultivation began. Second, retention of organic matter and subsequent levels of productivity in grassland soils is only possible if the correct proportions of carbon, nitrogen, and phosphorus are present (Peterson and Cole 1996). Agriculture usually requires extensive fertilizers to restore soil nitrogen levels. More than 6.4 million metric tons of nitrogen fertilizers were applied in the Mississippi Basin in 1991 (Goolsby et al. 1993). The harvesting of crops results in the removal of phosphorus that must be mitigated by fertilizers to maintain productivity. These fertilizers can increase concentrations of phosphorus in aquatic areas which can affect aquatic plant growth and reduce oxygen content in streams.

1.2.7 Water Resources

The SOPN has recognized from the beginning that the water resources of the network, whether in the form of precipitation or in water bodies, are a primary component of all the network ecosystems. Therefore, the monitoring of water has been integrated into the framework of the entire Vital Signs Monitoring Program.

Water has long been a scarce resource in the western and central portions of the Great Plains. Surface water is important for ecological reasons, but the presence of surface water was also important for European settlers. Eight of the 11 SOPN parks were created, at least in part, due to their cultural significance to Native Americans or early settlers. All of these cultural parks are located near flowing rivers because of the importance of water to Native Americans and early settlers. So while, surface water is a rarity in the Great Plains, SOPN parks have a higher proportion of surface waters then would occur on a random selection of prairie areas. Large reservoirs are one of the major resources for management and visitors at LAMR and CHIC. All SOPN parks except for Capulin Volcano NM, Alibates Flint Quarries NM, and Fort Union NM have permanent water resources, with the latter two being located very close to permanent water (Table 1.4).

Many of the basic features of historical Great Plains streams, such as flow and substrate, are unknown (Matthews 1988), as these were among the first things altered by early settlers. Great Plains streams fall into three categories: the shallow stream with shifting sand beds; clear brooks, ponds, and marshes supported by seeps and springs; and residual pools of intermittent streams (Cross and Moss 1987). In general, streams in the southern plains are characterized by irregular flow, small particle size in substrates and a distinct wet-dry cycle.

Arkansas River at Bent's Old Fort NHS

Great Plains Rivers generally flow from west to east and are characterized by extreme turbidity, high evaporation rates, moderate flow velocity and dynamic channels. Much of the water in the major rivers of the Great Plains originates from the western mountains. Many of the sediments in both rivers and streams originate from thunderstorm runoff on the Great Plains. Early travelers were inhibited by quicksands in small channels, fine particles held in suspension produced quicksands. These fine particles also cause extreme turbidity during low flows. Like the plains themselves, river temperatures can fluctuate widely with summer, open-river water temperatures exceeding

Table 1.4 Summary of water resources at the eleven National Park Service units within the Southern Plains Network.

Park	Major Water Bodies	Size Of Water Bodies That Lie Within SOPN Park Boundaries											
		Perennial Rivers		Intermittent Rivers		Adjacent Perennial Rivers		Lakes/Reservoirs		Lake/Reservoir Shorelines		Canal	
		Length (miles)	Impaired Length[1] (miles)	Length (miles)	Impaired Length (miles)	Length (miles)	Impaired Length (miles)	Area (acres)	Impaired Area (acres)	Length (miles)	Impaired Length (miles)	Length (miles)	Impaired Length (miles)
ALFL	Canadian River (intermittently flows)			3.61	0								
BEOL	Arkansas River, Arch Wetland, several small ponds	2.27	2.27										
CAVO	None												
CHIC	Lake of the Arbuckles, Veteran's Lake, several small streams & ponds	7.02	0	5.79	0			2503	0	36.8	0		
FOLS	Pawnee River	1.99	0	2.66	0								
FOUN	None within park (Wolf Creek is adjacent to Park)												
LAMR	Lake Meredith, Canadian River, several small streams & ponds	17.85	0	24.67	0			16242	16219	108.95	107.73		
LYJO	Pedernales River, Town Creek, stockponds	0.07	0	2.51	0	4.93	0	13	0	2.66	0		
PECO	Pecos River, Pecos tributaries, restored wetland	6.21	2.86	12.09	0.095								
SAND	Big Sandy Creek and wetlands	2.73	0	11.38	0							3.09	0
WABA	Washita River	0.92	0										
Σ of water body sizes in SOPN parks		39.06	5.13	62.71	0.095	4.93	0	18758	16219	148.41	107.73	3.09	0

[1] See Table 1.5 and Appendix I for description of impaired waters.

(NPS Hydrographic and Impairment Statistics, 2004)

Table 1.5 Waterbodies in the Southern Plains Network with 303(d) designation

Park	State	WBID[1]	Water Body	Portion Impaired	Impairment	Source of Impairment
BEOL	CO	COARLA01B	Arkansas River	From above Fountain Creek to Stateline (problems increase downstream); 2.27 miles	Selenium	Unknown/Natural
LAMR	TX	TX-0102	Lake Meredith	Nearly all of lake;16,218.84 acres	Mercury in Fish Tissue	Atmospheric Deposition
PECO	NM	NM-2214.A_003	Pecos River	From Canon de Manzanita to Alamitos Canyon; 2.86 miles	Temperature & Turbidity	Construction, Industry, urban and/or stormwater runoff, waste sites, mining

[1] Every State must assign a Water Body Identification (WBID) code to each body of water listed on their 303(d) list, which gets submitted to the Federal EPA.

30°C. High levels of salinity due to salt- and gypsum-laden groundwater are found in some areas.

The High Plains aquifer (Ogallala aquifer), consists of one or more geological units connected belowground under the central Great Plains, and is essential to agricultural, urban, and environmental resources. This aquifer contains about 20% of the irrigated farmland in the High Plains and about 30% of the water used for irrigation (Huntzinger 1996). Precipitation is the principal source of natural groundwater recharge, but recharge can also result from seepage loss from streams and lakes. Natural losses occurs as evapotranspiration from plants and soils where the water table is near the surface or as seepage to springs.

There have been significant changes in the amount and permanency of surface and ground water since pre-Columbian times as a result of ranching (e.g., stock ponds), irrigation, flood control, and other anthropogenic changes. Few major rivers in the Great Plains still exhibit the conditions evident before agricultural development and water management had occurred. Altered river hydrographs from dams, irrigation and municipal withdrawals, groundwater depletion, and other land use changes are a significant impact to aquatic systems in the Great Plains (Cross and Moss 1987, Longo and Yoskowitz 2002). Sediment deposition is part of reservoir design but remains a maintenance concern. In virtually all the river systems, dewatering has altered the timing and extent of flows, downstream temperatures, levels of dissolved nutrients, sediment transport and deposition, and the structure of plant and animal communities. Dams exist at three SOPN parks and all of the SOPN aquatic resources are affected by altered flows primarily from agriculture and development.

Water quality and quantity are high priority issues at SOPN parks. Water quality throughout the Great Plains has been affected by herbicides and other pollutants, and SOPN parks are no exception. Agricultural use of nitrogen fertilizers is the largest source of nitrates in near-surface aquifers in the midcontinent (Koplin et al. 1994). For example, over 100,000 metric tons of pesticides (herbicides, insecticides, and fungicides) were applied in the midcontinent in 1991, often to control nonindigenous plants and animals. Effects of these pollutants on the quality of human life and on the integrity of the ecological community are largely unknown. The U.S. Environmental Protection Agency has initiated an effort to develop stressor information to help recognize areas where urban development, agricultural nonpoint pollution (pesticides, toxic chemicals, nutrient pollution), and agricultural development may exacerbate ecological decline. Elevated *E.coli* levels, usually associated with fecal contamination, are also a concern at Chickasaw NRA.

Groundwater depletion is of regional concern for both Great Plains ecology and human needs. Kromm and White (1992) observed that groundwater depletion has destroyed much of the water-supported habitat for fish and mammals in parts of the Great Plains. They reported that more than 700 miles (1,127 km) of once permanently flowing rivers in Kansas no longer flow year round. The High Plains aquifer has declined from 1940 to 1980 by an average area-weighted, water-level decline of 9.8 feet (3 m) (2.75 inches per year (0.07 m/yr); Dugan et al. 1994). Local area declines have varied, exceeding 98 feet (30 m) in some parts of the central and southern High Plains; 19½ feet (6 m) in southwestern Kansas, east-central New Mexico, and the Oklahoma and Texas panhandles (Dugan et al. 1994). Subsurface water quantity and quality is an important resource and management issue at Chickasaw NRA and Bent's Old Fort NHS due to groundwater depletion from neighboring lands (primarily for irrigation and development) and potential development in Colorado Springs, many miles upstream from the park.

The NPS Government Performance and Results Act (GPRA) goal for water resources requires that parks report on "impaired waters" as defined by section 303(d) of the Clean Water Act. SOPN has three 303(d) listed waters (Table 1.5). A complete report of the water quality resources for SOPN is found in Appendix I.

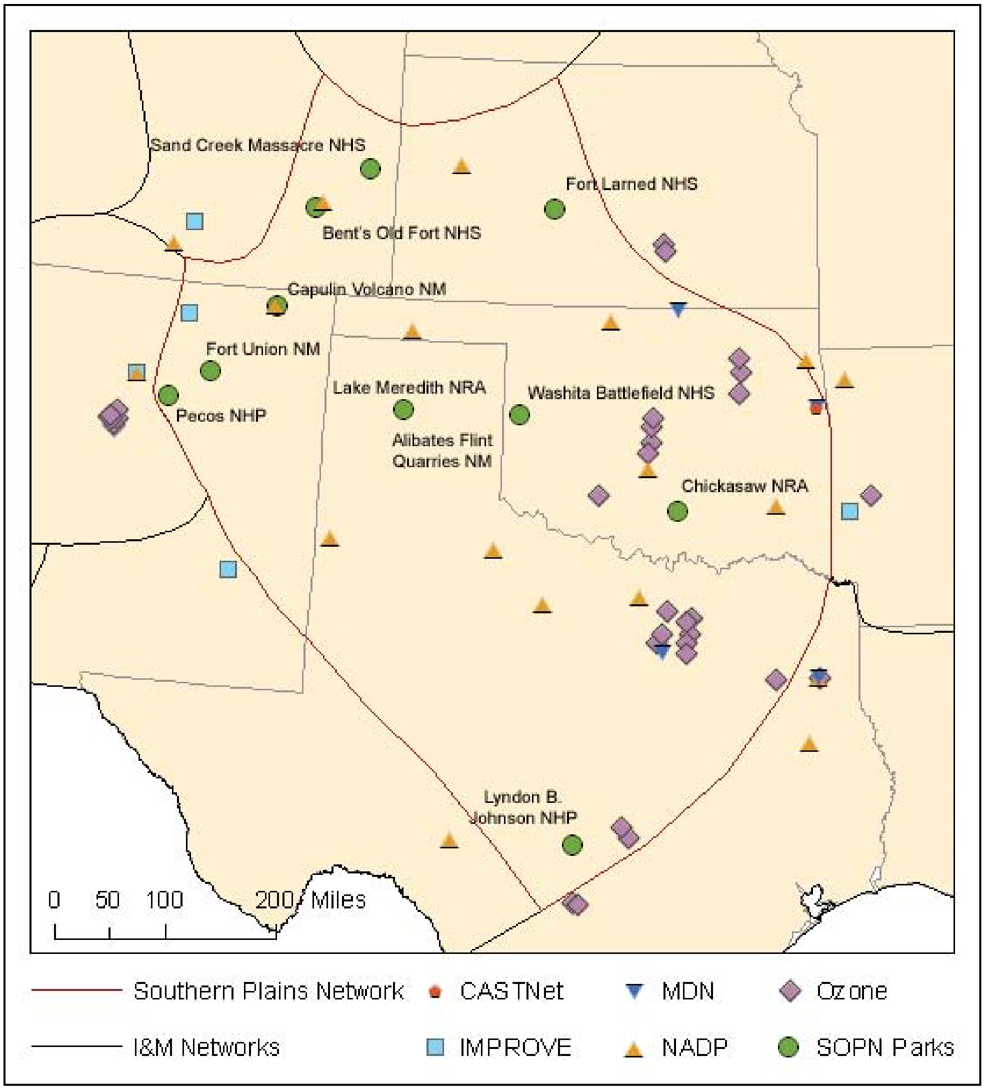

Figure 1.5 Air quality monitoring stations in, and in the vicinity of the Southern Plains Network

1.2.8 Air Quality

Under the Clean Air Act, park managers have a responsibility to protect air quality and related values from the adverse effects of air pollution. Protection of air quality in national parks requires knowledge about the origin, transport, and fate of air pollution, as well as its impacts on resources. To effectively protect park air quality, NPS managers need to know the type and level of air pollutants of concern, park resources at risk, and the potential or actual impact on these resources. Through the efforts of park personnel, support office staff, and the NPS Air Resources Division, the NPS meets its clean air affirmative responsibilities by obtaining critical data and using the results in regulatory-related activities.

The Great Plains is known for its clean air, distant horizons, and "big sky." Those characteristics are generally still true today as air resources in the region are less impacted than many other parts of the country. All SOPN parks are designated as Class II areas according to the Clean Air Act. However, increases in airborne pollutants such as nitrate, sulfate, and ammonium have been noted for the Great Plains region (Pohlman 2005). Many SOPN parks have cited air quality as a significant concern for natural and cultural reasons including ozone damage, pollutants, night skies and viewsheds.

SOPN park units are located in rural areas at large distances from cities and pollution sources. However SOPN parks still suffer from air pollutants. Some of the most common and abundant pollutant emissions include nitrogen oxides, and ammonia. Major sources of nitrogen oxides include cars and other mobile sources, compressors, power plants and industry. Agricultural activities are the main sources of ammonia. These air pollutants affect, or can affect, air quality and natural resources in SOPN, including vegetation, wildlife, soils, water quality, and visibility. High levels of ozone in the area, for example, may affect vegetation, as well as the health of park visitors and staff. Nitrogen compounds from the atmosphere have the potential to affect water quality and biota, soil nutrient cycling and plant species composition. Pollutant particles in the air reduce visibility in the region and affect the park viewshed. Atmospheric deposition of toxic organic compounds and metals, including mercury, may have a wide range of effects on fish and wildlife. A full description of SOPN air quality issues is found in Appendix L in Perkins et al. (2005).

There are no air quality monitors in the units, but nearby monitors may be representative of conditions in the network units (Figure 1.5). Types of monitoring include ozone monitoring by States (Ozone); wet deposition (rain, snow) monitoring of atmospheric pollutants by the National Atmospheric Deposition Program/National Trends Network (NADP/NTN); wet deposition monitoring of mercury by the Mercury Deposition Network (MDN); dry deposition (dryfall) monitoring of atmospheric pollutants by the Clean Air Status and Trends Network (CASTNet); and visibility monitoring by the Interagency Monitoring of Protected Visual Environments (IMPROVE) Program.

Ozone sensitive and bioindicator plant species have been identified for all of the SOPN units except Sand Creek Massacre NHS (a new park which is currently undergoing it's first ever plant inventory). Species were identified by plants present at each park with sensitive species identified according to USNPS (2003). Sensitive species are those that typically exhibit foliar injury at or near ambient ozone concentrations in fumigation chambers and/or are species for which ozone foliar injury symptoms in the field have been documented by more than one observer. Bioindicator species for ozone injury meet all or most of the following criteria: 1) species exhibit foliar symptoms in the field at ambient ozone concentrations that can be easily recognized as ozone injury by subject matter experts, 2) species ozone sensitivity has been confirmed at realistic ozone concentrations in exposure chambers, 3) species are widely distributed regionally, and 4) species are easily identified in the field. Based on a risk assessment developed from the risk of foliar injury due to presence of sensitive species, concentrations of ozone exceed an ambient threshold for injury, and environmental conditions foster gas exchange and uptake of ozone by the plant. Based on these factors Chickasaw NRA was designated as high risk, Lyndon B. Johnson NHP at moderate risk with all other parks designated as low risk.

1.2.9 Biotic Communities

Short-grass Prairie

The short-grass prairie extends east from the Rocky Mountains and south from Montana through the Nebraska panhandle and southeastern Wyoming into the high plains of Oklahoma, New Mexico, and Texas. On the east, short-grass prairie is bounded by mixed-grass prairie, on the west by the Rocky Mountains, to the south by shrub communities, and on the north by fescue grasslands, aspen forests and taiga. In the predominant clay soils, the SOPN short-grass prairie is dominated by blue grama and buffalo grass. Islands of sandy soils have taller grasses such as sand bluestem (*Andropogon hallii*) and switch grass. Weedy grasses include sand dropseed (*Sporobolus cryptandrus*), squirreltail (*Elymus elymoides*), and forbs (non-graminoid, non-woody dicots) such as curly cup gumweed (*Grindelia squarrosa*), and scarlet globe-mallow (*Sphaeralcea coccinea*) are also present (Weaver et al. 1996).

Less short-grass prairie has been converted to agriculture than tall- or mixed-grass prairie, although it has been heavily impacted by grazing. As much as 80% of the short-grass prairie has been lost in Texas (Samson and Knopf 1994). Overall, 48% of the short-grass prairie province has been lost to cropland or pastureland seeded with exotic grasses (Samson et al. 2004).

The short-grass prairie is typified by low stature, which is primarily due to low precipitation and an adaptation to heavy grazing (Coupland 1961) from bison, pronghorn, and elk, which occurred in large numbers (Howe 1994). Unlike the more eastern species, short-grass prairie species remain digestible and retain their protein content when dormant.

Short-grass prairie at Sand Creek Massacre NHS

Blue grama and buffalo grass are warm-season grasses that dominate the short-grass prairie and flourish under intensive grazing (Weaver et al. 1996); however, they respond very differently to disturbances. Buffalo grass reproduces both sexually and by tillering sprouts from the base of grass clumps and is sod-forming. It is capable of rapid growth through long rhizomes, however it has heavy burs that are produced among its leaves or near the soil surface which greatly limits seed dispersal. Buffalo grass colonizes local disturbed patches opportunistically with vegetative reproduction. This is a quick process that can result in recolonization of disturbed sites in a few years (Shantz 1917, Costello 1944). Blue grama is a slow-tillering bunchgrass with very short rhizomes, which limits its horizontal spread. However, it produces light seeds above the height of the canopy leaves (Riegel 1941) which can disperse long distances to colonize other sites.

In the short-grass prairie, long-term vegetative production is closely tied to precipitation (Lauenroth and Sala 1992). Rainfall ranges from 30 to 56 cm per year and there is generally a one to two month summer drought that is not as prevalent in the mixed and tall-grass prairies (Walter 1975). The most productive years are those when small precipitation events first stimulate nutrient availability, followed by large precipitation events that stimulate plant growth.

There is little known about fire in the short-grass prairie (Daubenmire 1968, Wright and Bailey 1982), but fire was thought to occur (Archer 1989). Fewer fires due to a reduction in grasses through overgrazing (Archer 1989) has likely resulted in invasions of honey mesquite in short-grass prairie in Texas (Sims 1988). Once mesquite becomes established it captures more water, so that grasses become patchy and lose productivity, therefore fire is reduced in frequency and intensity and it can no longer kill the mesquite seedlings (Weaver et al. 1996).

Extensive areas of short-grass prairie are now dominated by invasive perennial and annual species whose presence is attributed to overgrazing by domestic livestock and dryland farming (Weaver et al. 1996). These problems are potentially enhanced due to soil chemistry changes caused by increased atmospheric nitrogen deposition, fire suppression, and climatic anomalies (Seastedt 2002). In the Texas high plains, much of the short-grass prairie is now shrubland invaded by prickly pear cacti, mesquite, and oaks.

Mixed-grass Prairie

The short-grass and tall-grass prairies blend into a transition zone that runs from Texas through Oklahoma, Kansas, and Nebraska, northwestward into west-central North Dakota and South Dakota. Rainfall is generally 16-32 inches (40-80 cm) per year in the southern mixed-prairie. The boundary of the mixed-grass prairie is not well defined because of the wide array of short-stature, intermediate, and tall grass species that make up an ecotone between the short-grass and tall-grass prairies (Bragg and Steuter 1996). Drought and topography alter the species composition. In moist years the taller grasses increase, while in dry years buffalo grass and blue grama increase. Low to moderate levels of disturbance, such as grazing, and prairie dog digging can increase grassland diversity (Collins and Barber 1985). It is bordered by the tall-grass prairie to the east, short-grass prairie to the west, aspen parkland to the north, and juniper-oak savanna to the south (Küchler 1986).

In general, the mixed-grass prairie is characterized by the warm-season grasses of the short-grass prairie to the west and the cool- and warm-season grasses, which grow much taller, to the east. In the mixed-grass prairie there is a wide array of grasses, such as sideoats grama, little bluestem, blue grama, Indian grass, switch grass, big bluestem (*Andropogon gerardii*), sideoats grama, western wheatgrass, junegrass (*Koeleria cristata*), green needlegrass (*Stipa viridula*), tall dropseed (*Sporobolus asper*), Canada wildrye (*Elymus canadensis*), and sedges (Weaver and Albertson 1956, Wright and Bailey 1982) are dominant. Due to the transition between tall-grass and short-grass, the mixed-grass prairie has the highest plant species richness of the three prairie types. Grass species generally number in the 10s, but there are hundreds of forb species (Bragg and Steuter 1996). Forbs are generally more dynamic then the perennial grasses and respond to changes in moisture, grazing, and fire regimes (Biondini et al. 1989, Steuter et al. 1995). Blowout penstemon (*Penstemon haydenii*) is the only known endemic plant species to the mixed prairie and is confined to the Nebraska Sandhills (Stubbendieck et al. 1993). Samson et al. (2004) estimated that 46% and 79% of the historic mixed-grass prairie has been lost, and as much as 81% of the entire mixed-grass prairie province.

Mixed-grass prairie at Washita Battlefield NHS

The Edwards Plateau in south central Texas forms an ecotone between shrublands to the south and rolling plains to the north. The vegetation is dominated by scattered honey mesquite and lotebush (*Zizyphus obtusifolia*). The graminoid layer is dominated by buffalo grass (*Buchloe dactyloides)*, sideoats grama, little bluestem (*Schizachyrium scoparium*), and Texas winter grass (*Stipa leucotricha*) (Bragg and Steuter 1996). Oneseed juniper and ashe juniper are present along escarpments and can invade other areas when they are overgrazed and fires are suppressed. These species can increase under heavy grazing as the fire fuel is decreased and fires can no longer burn hot enough to reduce the junipers. Junipers then begin to shade out grass species and can substantially reduce forage availability (Wink and Wright 1973, Steuter and Wright 1983).

The historical fire frequency patters for this area was a 5-8 year rotation. Fire in the mixed-grass prairie alters species diversity patterns (Biondini et al. 1989) and modifies grazing patterns (Coppock and Detling 1986) subsequently affecting the fauna (Bragg 1995). Fire and grazing combine to exaggerate drought stress on the native vegetation (Mihlbacher et al. 1989). In Kansas and Oklahoma it may take the grasses only 1-3 years to recover from fire (Launchbaugh 1973, Nagel 1983), depending on the season of burn. Most grasses tolerate fire well in average to wet years but are reduced substantially when fires occur in drier years (Hopkins et al. 1948, Wink and Wright 1973, Wright 1974). Burning mixed-grass more then every 5-8 years will likely reduce stands of the dominant herbaceous species (Sharrow and Wright 1977, Neuenschwander et al. 1978). In Texas, fire is very important in preventing mesquite and juniper from invading (Wink and Wright 1973, Neuenschwander et al. 1978, Steuter and Wright 1983).

Grazing generally reduces the standing crop in mixed-grass (Milchunas and Lauenroth 1993). Under heavy grazing the tall-grass species are reduced and the short-grass species increase. Moderate grazing may actually increase productivity (Tomanek and Albertson 1957) in mixed-grass prairie. When grazing is stopped, there is a subsequent reduction in productivity due to increased litter accumulation.

Streams and Rivers (Riverine Systems)

The study of prairie streams and rivers is still in the ecological exploration stage when compared to the knowledge known about forested streams and the standard River Continuum Concept (Vannote et al. 1980) may not apply to prairie streams. The most detailed work on prairie streams has been completed at King's Creek located at the Konza LTER site in tall-grass prairie (Gray and Dodds 1998, Gray et al. 1998), with less work occurring in the mixed- and short-grass prairies.

Most watersheds in the SOPN drain the eastern slope of the Rocky Mountains and flow from west to east, traversing plains of Quaternary sediments underlain by the Ogallala aquifer (Eschner et al. 1983). Prairie streams and rivers are usually characterized by stable flows during spring and early summer, and intermittent flow to completely dry in the summer. Floods can scour the channel at any time. Flow in the main stem of rivers during early summer is derived from snowmelt runoff, which can decline and leave some channels intermittent during the summer (Jordan 1891, Mead 1896, Eschner et al 1983, Cross et al. 1985). In the plains tributaries, the flows come primarily from spring rains and summer thunderstorms which produce flash floods. These floods are exacerbated in many areas due to impermeable soils that produce high runoff (Fausch and Bramblett 1991).

Historically rivers would have resulted in narrow gallery forests. However these riparian forests have expanded since pre-European times (Wedel 1986, Knopf and Scott 1990). Fringe riparian forests would have cycled on 50-150 year intervals (Scott et al. 1996) due to large runoff periodically eliminating woody species and contributing large woody debris to channels. Some streams in the west may have been almost devoid of trees. As the stream flow varies, so does physicochemical variables such as water temperature, dissolved oxygen, turbidity, and salinity (Matthews and Zimmermann 1990). Channel beds of large rivers were historically shifting sand, wide and shallow with braided shifting sand beds that formed numerous bars and islands, and turbid water due to the high sediment load (Cross and Moss 1987, Bramblett and Fausch 1991a). The biotic community that has evolved with prairie streams has developed the ability to adjust to a patchy environment that is created by the variable stream flow and associated large changes in temperature and turbidity.

Canadian River at Lake Meredith NRA

Variable stream flows and regular droughts create a particularly harsh environment for fish. Little is known about the original distributions and ecology of many fish in the Great Plains because habitats were drastically altered before observations had been made (Eschner et al. 1983). Great Plains fish species can be characterized by being relatively small (<8 inches (200 mm)), highly vagile, having life spans <6 years, and being well-adapted to withstand floods and extremes during droughts (Fausch and Bestgen 1997). Most plains fish species are generalists that occupy habitats and consume food resources in proportion to what is available (Bramblett and Fausch 1991b).

Development progressed rapidly with the discovery of gold in the mountains west of Denver in 1858. Water development began with small ditches that were followed by larger canals for irrigating terraces in the 1840's to 1860's. Since some of the rivers went dry, reservoirs were built in the late 1800's and early 1900's. With the demand for water still increasing, groundwater began being pumped from the Ogallala aquifer in the 1930's

(Fausch and Bestgen 1997). These water development projects had drastic effects on river channels, including narrowing, and becoming more sinuous due to encroaching vegetation (Nadler and Schumm 1981). Reduced runoff allowed seedlings of woody vegetation to stabilize shifting sand bars. The vegetated sand bars trapped sediment and eventually attached to the floodplain, changing the straight wide braided channels to single narrow sinuous ones. The increase in cottonwood riparian forests now contributes more woody debris to the stream channel then historic levels. The creation of the John Martin Reservoir on the Arkansas River in 1942 combined with groundwater pumping in Colorado and western Kansas completely eliminated flow in 100 miles (160 km) of the Arkansas River, except for discharge from municipal wastewater treatment plants (Fausch and Bestgen 1997).

Reservoirs (Lacustrine Systems)

Reservoir systems are the principal resources at LAMR and CHIC, and therefore drive many of those Park's management decisions and visitor usage. Additionally, the Pedernales River is impounded by three dams in, and adjacent to LYJO. These artificial lakes were originally designed to satisfy the increasing need for water resources. They supplied water to surrounding municipalities, industries, agricultural communities, and regulated stream flow. Today, reservoirs continue to satisfy the well-defined economic objectives for which they were developed. However, reservoir systems are posing challenges to natural resource managers, including those at CHIC, LAMR, and LYJO. When reservoirs replace riverine ecosystems, new physical and biological conditions are created which managers must then protect and preserve. Reservoirs have unique operational and maintenance characteristics compared to those of natural lakes (Flug 1998).

Lake of the Arbuckles at Chickasaw NRA

The effects that reservoirs have upon the surrounding natural ecosystems are broad. For example, man-made reservoirs, unlike natural lakes, tend to experience large fluctuations in water levels, and are highly susceptible to bank instability and erosion (Flug 1998). The dam at Lake Meredith NRA has resulted in large scale changes in the fish community upstream and downstream of the dam (Bonner and Wilde 2000). Furthermore, reservoirs trap river sediments, often create deltas at the mouth of river inflows, alter water quality and temperature, create habitat for non-native fish species, present an obstacle to native fish migration, and may create wetlands or new riparian resources (Flug 1998). For recreational users, reservoirs provide lake resources that include swimming, boat access, beaches, and sport fishing; however, the reservoir may have displaced historical viewsheds.

The effects of large dams on natural rivers downstream are well documented (Vanoni 1975). Typically, rivers downstream from large dams experience fewer and smaller floods. Water released below dams may cause erosion that degrades the stream bed, removes or erodes alluvial bars, and degrades or cuts into vegetated stream banks. Downstream geomorphology changes when tributary inflows contribute substantial amounts of sediment that cannot be transported by the decreased flows of the main channel. This sediment imbalance can alter river substrates, increase width-to-depth ratios, form channel bars, and increase lateral instability (Flug 1998). Other characteristics of water quality and temperature released from reservoirs include such things as lower turbidity, which alters light penetration in turn affecting primary production and fish and macroinvertebrate habitats.

Regulated flow releases from dams can provide benefits for boating and swimming, extreme fluctuations can be detrimental to recreational water use. These fluctuations also favor non-native vegetation species that may proliferate and out-compete native species that have evolved and adapted to natural flow cycles and stream dynamics (Flug 1998).

Prairie Wetlands (Palustrine Systems)

Emergent wetlands naturally form in places where groundwater discharges or surface water collects for some time in a manner sufficient to saturate soils. Such places in the Great Plains include depressions surrounded by upland and sloped areas below sites of groundwater discharge. Small prairie wetlands play an important role in Great Plains hydrology by storing surface water, moderating floods, improving water quality, and by recharging ground water and soil moisture. These wetlands are also highly productive habitat for waterfowl and other wildlife in a generally arid region. The disruption of natural processes such as fire and grazing since pre-European times has led to domination of these wetlands by robust, emergent plants. Climate, fire, and grazing previously controlled the diversity and abundance of vegetation in prairie wetlands. As these processes have changed, belowground seed reserves favor those species with seeds that germinate under a wide range of conditions, such as cattail, purple loosestrife, and other nonindigenous species. Cattail, once rare on the Great Plains, has spread across thousands of prairie wetlands.

Arch Wetland at Bent's Old Fort NHS

Persistent emergent wetlands (freshwater marshes) (Cowardin et al. 1979) are the major type of palustrine wetland within SOPN and are present at BEOL, SAND, CHIC, PECO, and LAMR. These wetlands are dominated by persistent vegetation present for most of the growing season in most years. The vegetation generally remains standing from one year to the next. Wetlands without persistent vegetation are also included in this system if they are < 20 acres (8 ha), < 6.7 feet (2 m) deep during low water times, and where no portion of the boundary contains wave-formed or bedrock shoreline. Freshwater marshes are characterized by: 1) emergent, soft-stemmed aquatic plants such as cattails, arrowheads, reeds, and other species of grasses and sedges; 2) a shallow water regime; and 3) generally shallow deposits of peat. These wetlands are usually dominated by perennial plants.

In the Great Plains wetlands comprise a small portion of the landscape, but they are often the areas of highest species diversity. Despite comprising <10% of the landscape in North America (on an areal basis), wetlands are important habitat for 68% of birds, 66% of mussels, and 75% of amphibians on the U.S. list of threatened and endangered species (Mitsch and Gosselink 2000). Wetland losses have been extensive in the SOPN Region. Dahl (2000) estimated that between 51 and 75% of wetlands had been lost in Texas and Oklahoma and between 25 and 50% in Kansas, Colorado, and New Mexico. Agriculture and urbanization are the dominant human influences on Great Plains wetlands.

Agricultural activities outside park boundaries pose threats to wetlands with SOPN parks. Runoff contaminated with sediment, nutrients, and pesticides reach park wetlands through waterways and drainages that have inadequate buffer zones. Aerial deposition of pesticides and nutrients has been documented in wetlands downwind of agricultural areas. Wetland destruction and fragmentation on adjacent lands threatens wetland species dependent on migration or dispersal corridors. The primary stressors associated with agricultural activity are drainage, sediments, nutrients, and toxicants.

Piñon-Juniper Forests

Piñon-juniper forests cover a significant portion of Western and Southwestern United States (Davenport et al. 1998). This forest type only occurs in two SOPN parks, however, these forests are the dominant ecosystem at PECO, and represent some of the eastern-most populations of this forest type at CAVO. Stands of piñon-juniper forests are most often found in arid to semi-arid watersheds. These forests are capable of surviving on a variety of soil types ranging from aridsols, mollisols to entisols that have formed from basalt, limestone, and sandstone parent materials (Wilcox and Davenport 1995).

Piñon-juniper forests are characteristically comprised of relatively small, xeric coniferous trees, which tend to be drought-resistant and cold-tolerant, and that form an open canopy. The understory will likely consist of mixed grasses and shrubs. The composition and relative dominance of the contrasting functional groups that form the canopy and the ground cover will highly influence piñon-juniper ecosystems (Whitford 2002, Breshears and Barnes 1999).

Piñon-juniper forests can provide unique and often irreplaceable ecological services, including plant and animal habitats, food for herbivores, nutrient cycling, and water capture and retention (Whisenant 1999, Whitford 2002). However, piñon-juniper forest ecosystems have exhibited widespread and rapid changes over the past century, which has often produced adverse ecological effects and caused interruptions to their ecological services. In particular, increased woody-plant density and range expansion have facilitated erosion, debilitated soil processes, eliminated habitat, and diminished forage productivity (Pieper 1990, Kerkhoff et al. 2004). An additional concern of increasing woody-plant density that park managers are currently facing is the recent infestation of the Ips beetle (*Ips confuses*), which is taking advantage of the changes in piñon-juniper forest communities.

As shrub steppe communities are converted to juniper woodlands, community structure, composition, function, disturbance patterns, and wildlife habitat are altered. Several authors have cited overgrazing, fire suppression, climatic change, and the complex interactions between the three, as the predominant reasons for the drastic physiognomic shifts that have been occurring in piñon-juniper forests since the mid-1900's (Archer et al. 1999, Munoz-Erickson et al. 2002). In particular, the encroachment of the aggressive piñon-juniper (Tausch and Tueller 1990) upon grasslands at low elevations and ponderosa pine stands at high elevations has occurred throughout much of the region and is a management concern at CAVO and PECO. The challenge is to identify reliable plant and soil parameters that can be monitored in the dynamic piñon-juniper woodlands to anticipate and adjust land-use practices accordingly (Archer et al. 1999).

Piñon-juniper forest at Pecos NHP

1.2.10 Land Use / Land Cover Issues

Landscape ecology focuses on patterns and processes at multiple spatial and temporal scales of the landscape mosaic. It is concerned with processes that cross boundaries of homogenous and heterogeneous ecological systems and their use. Landscape ecology is particularly important to grassland systems as they have evolved to a shifting mosaic of successional stages as the grassland is continually reset by disturbances from fires, drought and grazing. Landscape ecology of SOPN parks is particularly important due to their small size. The ecological communities within SOPN parks are as influenced by the ecological processes and anthropomorphic activities that occur outside of park boundaries as they are by management within the park. Monitoring the ecological effects of landscape dynamics is a difficult task for natural resource managers. The ecological processes affecting the landscape can occur at different spatial and temporal scales, depending on the process of interest.

Fires affect landscape patterns due to a variable distribution of factors such as fuel, soil moisture, and wind patterns which would result in heterogeneity of the burned area that would in turn affect plant composition, small mammal and bird communities. Physical features such as areas recently heavily grazed by bison, prairie dog towns, buffalo wallows can interact with fires by creating unburned areas that can serve as refugia for plants and less-vagile animals. Post burn, the leaching of nutrients by heavy rains may enhance productivity in streams while reducing nutrients in uplands needed for regrowth. This patchiness would affect the ungulate distribution post fire as many preferentially graze burned areas due to higher nutritive quality and the removal of standing dead material and deep litter (Risser 1990).

Human processes appear to be one of the major stressors on SOPN ecosystems, interrupting several key processes, like fire and grazing that maintained the grassland ecosystem. Human development has also fragmented the landscape, which decreased the size of the functional ecosystem, reduced connectivity among native habitat patches, isolated species in small patches, and introduced edge effects across the landscape. These disruptive processes lower the fitness of native species residing in the park, which increases the probability of extinction within the park.

There are some ecological processes that are operating at spatial and temporal scales broader than the Great Plains. The Great Plains has well known gradients of increasing precipitation from west to east and decreasing temperatures from south to north. Changes in global climate may alter these gradients and subsequently alter landscape patterns. Atmospheric constituents can influence vegetation composition. Acidification via sulfide dioxide (SO_2) pollution has altered the grassland community (Heil et al. 1988, Lauenroth and Preston 1984). More recent concerns involve acidification caused by increased nitrification from increased nitrogen deposition, and this phenomenon may be amplified on nutrient poor sites.

1.2.11 Human History

The Great Plains have been an important area for agriculture, recreation, and human expansion over the last 150 years. Accurate depictions of what the prairie was like prior to European settlement are difficult to decipher. It is thought that any historic record dated after 1770 provides a view of an altered landscape because the ecosystem had already been altered due to increased European use along riparian corridors, introduction of diseases that were detrimental to indigenous nations, and a change in bison behavior (Higgens 1986). All three of these factors had a dramatic effect on the historic landscape (Nasatir 1952). Interestingly, all SOPN cultural parks have designated periods of significance after this 1770 date, and therefore the management goals at these parks are to achieve a landscape that had already been dramatically altered by Europeans.

Fort ruins at Fort Union NM

As settlers first moved west, some took delight in the abundant fauna while others were depressed by the solitude and never-ending fields of grass. These settlers quickly altered the faunal communities. Lieutenant Colonel Richard I. Dodge (Smith County Pioneer 1877) wrote:

> *"The most delightful hunting…I have ever had was in the country south-east of Fort Dodge on the small tributaries of the Cimarron River. I append the record of a hunt of twenty days in the section, in October 1872, in which one officer besides myself and three English gentlemen participated. Everything bagged was counted as one, and an idea of the spot can be formed from this list: 127 buffalo, 2 deer, 11 antelope, 154 turkeys, 5 geese, 223 teal, 45 mallard, 49 shovel-bill, 57 widgeon, 38 butter-ducks, 3 shell-ducks, 17 herons, 6 cranes, 187 quail, 32 grouse, 84 field-plover, 33 yellow legs (snipe), 12 jack snipe, 1 pigeon, 9 hawks, 3 owls, 2 badgers, 7 raccoons, 11 rattlesnakes, 143 meadow larks, doves, robins etc, and 1 bluebird for his sweetheart's hat. Total head bagged: 1,262."*

The bison were quickly decimated as Europeans settled the plains. Railways gave hunters easy access to bison herds and easy transportation to markets in the east. Lt. General Phil Sheridian told the Texas legislature that buffalo hunters were doing more to:

> *"settle the vexed Indian question than the entire regular army… for the sake of a lasting peace let them kill, skin, and sell until the buffaloes are exterminated. Then your prairie can be covered with speckled cattle, and the festive cowboy, who follows the hunter as the second forerunner of an advanced civilization."*

The Homestead Act of 1862 may be the single most significant impact to the Great Plains (Ostlie et al. 1997). Nearly 1.5 million people acquired over 308,880 square miles (800,000 km^2) of land in the Great Plains under this act. The land made available under this act and other federal acts resulted in a huge loss in native prairie as it was converted to row-crop agriculture. The largest effect was in the tall-grass prairie but this conversion was felt throughout the Great Plains. As much as 70% of the Great Plains grasslands may have been lost. Losses were less in areas within SOPN, ranging from 69% loss in the Edwards Plateau of Texas, to 46% in the central mixed prairie to 36% and 45% loss in the central and southern short-grass prairie, respectively (Samson et al. 2004). These losses are not just restricted to settlement times, Samson et al. (2004) estimated that 36,000 square miles 93,000 km^2 of grasslands were converted to agriculture between 1982 and 1997.

Many changes in the ecosystem have resulted due to the intensification of land use by humans. Today the short-grass prairie is predominantly used for grazing and the mixed-grass prairie comprises the "wheat belt". There have also been large changes in the faunal community. Many birds have moved into the region due to human practices (tree planting, agriculture, development). In contrast, some native species are still heavily persecuted and managed because of perceived and real competition with current land use practices (e.g., prairie dogs).

Agriculture is still the most important industry with ranching predominating in the western portion of the region and farming predominating in the eastern portion of SOPN, although the ownership has changed from small family farms to consolidated large farms owned by corporations. Wildlife resources still present in the region are valued by local residents, especially game species. In some areas, profits from hunting leases exceed those from agriculture. This has led to other problems as high fencing that is put up to protect exotic game and trophy quality native game. These fences increase income, but they fragment populations of medium and large sized mammals. Mineral and energy development are important locally, especially in western Oklahoma and the Texas Panhandle. Urban development occurs at relatively slow rates, although urbanization is still a concern at Chickasaw NRA, Lake Meredith NRA, and Lyndon B. Johnson NHP. Many SOPN park units are located significant distances from the nearest towns with year-round services. Chickasaw NRA is the only park unit directly abutting an urban area. Despite the large distances from urban centers, light development near park boundaries is a concern for some park units as a small new development can have a very large impact on the night sky for parks in rural areas.

Today, the Southern Plains Network is located in an area dominated by agriculture and low populations that is devoid of major cities. The Great Plains still is somewhat separated culturally due to its rural nature. In 1931, Walter Prescott Webb said the Plains began at the 98th meridian and west of this line all of the eastern ways of life and living were "either broken and remade or else greatly altered". In recent decades, human population has declined in many rural areas dependent on agriculture (Popper and Popper 1987, Licht 1997) and the median age of some communities has risen to the 60s. This decline in population has led some to propose or predict a return to large areas of land dedicated to wildlife conservation (Popper and Popper 1994, Bock and Bock 1995, Callenbach 1996, Licht 1997, Forrest et al. 2004).

1.3 VITAL SIGNS – PARK NATURAL RESOURCES AND MANAGEMENT PRIORITIES

This section presents SOPN's approach to developing the initial list of potential vital signs. Important management issues for SOPN parks were identified through a variety of methods; including park-based scoping sessions, an issue/stressor survey, a survey of park planning documents, review of peer-reviewed literature, and ecosystem workshops and reviews.

1.3.1 Park Based Scoping

SOPN staff visited all 11 SOPN parks from January through May, 2004. At each park, natural resource staff gave SOPN a tour and overview of the park natural resources and SOPN collected information in the form of reports, maps, and GIS coverages. SOPN then gave an overview presentation to park staff and SOPN staff held a park scoping session. A total of 64 people attended these presentations.

The actual scoping session was in the form of an interview and discussion that covered the important natural resource issues and their stressors, discussion of current and historic monitoring projects in and around the park, potential partners, outside scientists with expertise in the park, natural resource needs, and ways to best communicate with parks. SOPN invited the natural resource staff plus superintendents to the scoping meeting. Parks were welcome to invite any additional staff or outside people they thought would be pertinent to the discussion. Thirty-four park staff participated in the scoping sessions. In addition, scoping session questionnaires were sent to an additional 11 people who the park specified as having experience with park natural resources. These sessions allowed SOPN to hear directly from the park staffs what their most important resources were and their initial thoughts on their biggest monitoring needs. This information was essential in laying the foundation for a monitoring program that will meet park needs. Reports of the park-based scoping sessions are in Appendix M of Perkins et al. (2005).

1.3.2 Issues Identified in Park Documents

An extensive review of park planning documents was completed in 2004 and 2005. This review included General Management Plans, Resource Management Plans, Fire Management Plans, Integrated Pest Management Plans, administrative histories, gray literature, and enabling legislation (often as interpreted through planning documents) for all eleven SOPN parks. These documents set the local mandates for management in these units, and are therefore directly relevant to ecological monitoring.

1.3.3 Natural Resource Issue / Stressor Survey

Upon completing the scoping sessions, SOPN staff compiled lists of all the natural resources and stressors that were identified from all 11 parks. SOPN then added resources and stressors to this list that were discovered during the literature review. This information was then converted into an access database. The database was sent out to the technical committee representative in order to rank each resource and stressor to one of the following rankings: high priority, priority, issue at park – but low priority, and not an issue. SOPN requested that the parks try to limit their high priority rankings to less then five issues and five stressors. The responses were compiled to create a prioritized list of natural resources and stressors for each individual SOPN park and for the SOPN as a whole. A complete list of the 85 ranked issues is found in Appendix O.

1.3.4 Ecosystem Workshops and Reviews

In 2005, SOPN held two ecosystem workshops. The workshops brought together representatives from each park and subject-matter experts from state and federal agencies, universities, and non-profits. The objectives of the workshops were to: 1) review draft conceptual models (see chapter 2 for descriptions on conceptual models) and provide suggestions for modifications and possible additional models; 2) review the access database of natural resources and stressors of the network; and 3) to develop and review the list of potential vital signs and their preliminary justification statements and monitoring objectives. Each workshop lasted two days. All parks were represented at each workshop and a total 31 outside experts attended. The first workshop was divided up into a mixed-grass and short-grass workgroup. The second workshop had three workgroups: reservoirs, rivers and streams, and landscape issues (land cover, air quality, land uses). A report was written up and sent to all participants for review at the conclusion of the workshop (Appendix P in Perkins et al. 2005).

1.3.5 Network Wide Issues

The above approach allowed park-specific information to receive multiple layers of review and evaluation. This process led to the identification and aggregation of issues important at both the network and park scale. These workshops made a preliminary determination of high priority issues across the network (Table 1.6). The workgroups ranked an issue as high only if there was consensus among group members. Ratings from the five

Table 1.6 Issues identified as high priority across the network according to workgroups at the Grassland, and Aquatic and Landscape Workshops

Issue Name	Mixed-Grass	Short-Grass	Rivers and Streams	Reservoirs	Landscape
Exotic Plants	●	●	●	●	●
Grassland Community	●	●			
Carbon Balance	●				
Prairie Restoration	●	●			
Water Quality	●	●	●	●	
Water Quantity	●	●	●		
Weather Patterns	●	●			●
Woody Invasive Species	●	●			●
Fire Dynamics		●			●
Grassland Birds		●			
Effects of Park Visitors		●			
Erosion	●		●	●	
Exotic Ungulates	●				
Viewshed		●			●
Groundwater Levels			●	●	
Arkansas River Shiner			●		
Upland Springs Community			●		
Riparian Community			●		
Cottonwood Community			●		
Riverine Community			●		
Lacustrine Community				●	
Native Species Communities					●
Zebra Mussels			●		
Landscape Dynamics					●
E. Coli				●	

workgroups resulted in 23 high priority network issues out of a total of 93 issues that were reviewed.

1.3.6 Park Specific Issues

In addition to the network wide issues, there are potential vital signs that should be considered in vital signs selection that are not high priority for the network but are very high priority for an individual or group of parks. Table 1.7 is a list of 25 issues that were ranked as high priority by an individual park based on scoping sessions and subsequent natural resource/issue survey, but were not identified as high at the workshops.

1.4 MONITORING DESIGN AND THE THREE PHASE PROCESS

1.4.1 Designing an Integrated Monitoring Program for SOPN

Monitoring is an on-going effort to better understand how to sustain or restore ecosystems, and serves as an "early warning system" to detect declines in ecosystem integrity and species viability before irreversible loss has occurred. One of the key initial decisions in designing a monitoring program is deciding how much relative weight should be given to tracking changes in focal resources and stressors that address current management issues, versus measures that are thought to be important to long-term understanding of park ecosystems. Should vital signs monitoring focus on the effects of known threats to park resources or on general properties of ecosystem status? Woodley et al. (1993), Woodward et al. (1999), Jenkins et al. (2002) and others have described some of the advantages and disadvantages of various monitoring approaches, including a strictly threats-based monitoring program, or alternate taxonomic, integrative, reductionist, or hypothesis- testing monitoring designs (Woodley et al. 1993,Woodward et al. 1999). The approach adopted by SOPN agrees with the assertion that the best way to meet the challenges of monitoring in national parks and other protected areas is to achieve a balance among different monitoring approaches (termed the "hybrid approach" by Noon 2003), while recognizing that the program will not succeed without also considering political issues. A multi-faceted approach for monitoring park resources was adapted, based on both integrated and threat-specific monitoring approaches and building upon concepts presented originally for the Canadian national parks (Figure 1.6; Woodley et al. 1993). This system segregates indicators into one or more of four broad categories:

1. ecosystem drivers that fundamentally affect park ecosystems;
2. stressors/threats and their ecological effects;
3. focal resources of parks; and
4. key properties and processes of ecosystem integrity.

In cases where there is a good understanding of relationships between potential effects and responses by park resources (known effects), monitoring of system drivers, stressors, and effected park resources is conducted. A set of focal resources (including ecological processes) will be monitored to address both known and unknown effects of system drivers and stressors on park resources. Key properties and processes of ecosystem status and integrity will be monitored to improve long-term understanding and potential early warning of undesirable changes in park resources.

Natural ecosystem drivers are major external driving forces such as climate, fire cycles, biological invasions, and hydrologic cycles that have large scale influences on natural systems. Trends in ecosystem drivers will have corresponding effects on ecosystem components may provide early warning of presently unforeseen changes to ecosystems.

Table 1.7 High priority issues identified by individual parks not on the network-wide list of high priority issues

Park	High Priority Issues
ALFL	Night Sky, Soundscape, Texas Horned Lizard
BEOL	Effects of Wildlife Diseases on Visitors and Resources, Flooding Processes, Wetland Community
CAVO	Montane-Grassland Ecotone Community, Cryptobiotic Soils, Alberta Arctic Butterfly
FOLS	Small Mammal Community, Black-Tailed Prairie Dogs
LAMR	Texas Horned Lizard, Big Game
LYJO	Fire Ants
PECO	Effects of Insect Outbreaks, Feral Dogs, Big Game, Reptile Community, Migratory Songbird Stopover Area, Bald Eagle, Large Carnivores
SAND	Effects of Grazing
WABA	Soundscape

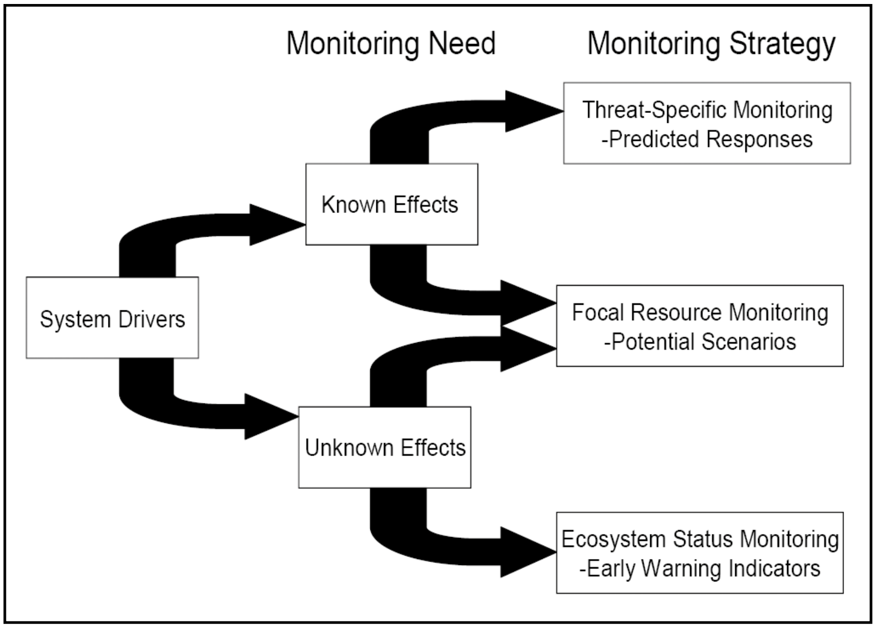

Figure 1.6 Conceptual approach for selecting monitoring indicators (From Woodley et al. 1993)

Stressors are physical, chemical, or biological perturbations to a system that are either (a) foreign to that system or (b) natural to the system but applied at an excessive [or deficient] level (Barrett et al. 1976). Stressors cause significant changes in the ecological components, patterns, and processes in natural systems. Examples include water withdrawal, pesticide use, grazing levels, traffic emissions, stream acidification, trampling, poaching, land-use change, and air pollution. Monitoring of stressors and their effects, where known, will ensure short-term relevance of the monitoring program and provide information useful to management of current issues.

Focal resources, by virtue of their special protection, public appeal, or other management significance, have paramount importance for monitoring regardless of current threats or whether they would be monitored as an indication of ecosystem integrity. Focal resources might include ecological processes such as deposition rates of nitrates and sulfates in certain parks, or they may be a species that is harvested, endemic, alien, or has protected status.

Our current understanding of ecological systems, and consequently, our ability to predict how park resources might respond to changes in various system drivers and stressors is poor. A monitoring program that focuses only on current threat/response relationships and current issues may not provide the long-term data and understanding needed to address high-priority issues that will arise in the future. Ultimately, an indicator is useful only if it can provide information to support a management decision or to quantify the success of past decisions, and a useful ecological indicator must produce results that are clearly understood and accepted by managers, scientists, policy makers, and the public.

1.4.2 The Three Phase Process

The complicated task of developing an integrated monitoring program requires an initial investment in planning and design to: 1) guarantee that monitoring meets the most critical information needs of each park; 2) produces scientifically credible results that are clearly understood and accepted by scientists, policy makers, and the public; 3) make results readily accessible to managers and researchers. The planning process must also ensure that monitoring builds upon existing information and understanding of park ecosystems while maximizing relationships with other agencies and academia.

Each network of parks is required to design an integrated monitoring program to address the monitoring goals listed above; one that is tailored to the high-priority monitoring needs and partnership opportunities for the parks in that network. Although there will be considerable variability among networks in the final design, the basic approach to designing a monitoring program should follow five basic steps:

1. Define the purpose and scope of the monitoring program.
2. Compile and summarize existing data and understanding of park ecosystems.
3. Develop conceptual models of relevant ecosystem components.
4. Select vital signs and specific monitoring objectives for each; and
5. Determine the appropriate sampling design and sampling protocols.

These steps are incorporated into a 3-phase planning and design process that has been established for the network monitoring program. Phase 1 of the process involves defining goals and objectives; beginning the process of identifying, evaluating and synthesizing existing data; developing draft conceptual models; and completing other background work that must be done before the initial selection of ecological indicators. Each network is required to document these tasks in a Phase 1 report, which is then peer reviewed and approved at the regional level before the network proceeds to the next phase. Phase

2 of the planning and design effort involves prioritizing and selecting vital signs and developing draft monitoring objectives for each that will be included in the network's initial integrated monitoring program. Phase 3 entails the detailed design work needed to implement monitoring, including the refinement of specific monitoring objectives, development of sampling protocols, a statistical sampling design, a plan for data management and analysis, and details on the type and content of various products of the monitoring effort such as reports and websites. The schedule for completing the 3-phase planning and design process is shown in Table 1.8.

1.4.3 Limitations of Monitoring

Managers and scientists need to acknowledge limitations of the monitoring program that are a result of the inherent complexity and variability of park ecosystems, coupled with limited time, funding, and staffing available for monitoring. Ecosystems are loosely-defined assemblages that exhibit characteristic patterns on a range of scales of time, space, and organization complexity (De Leo and Levin 1997). Natural systems as well as human activities change over time, and it is extremely challenging to separate the natural variability inherent to ecosystems from the undesirable changes in park resources and ecosystems that may result from anthropogenic causes.

The monitoring program simply cannot address all resource management interests because of limitations of funding, staffing, and logistical constraints. Rather, the intent of vital signs monitoring is to monitor a select set of ecosystem components and processes that reflect the condition of the park ecosystem and are relevant to management issues. Cause and effect relationships usually cannot be demonstrated with monitoring data, but monitoring data might suggest a cause and effect relationship that can then be investigated with a research study. As monitoring proceeds, as data sets are interpreted, as our

Table 1.8 Timeline for monitoring plan development and implementation in the Southern Plains Network. Colors to the left of text represent the duration of the cited activity (e.g. Protocol Development and Monitoring Design will take place from April FY06 through September 2008)

FY04		FY05		FY06		FY07		FY08		FY09
Oct-Mar	Apr-Sep	Oct-Mar	Apr-Sep	Oct-Mar	Apr-Sep	Oct-Mar	Apr-Sep	Oct-Mar	Apr-Sep	Oct-Mar
Inventories to support Monitoring										
Data Gathering										
Park-Based Scoping Sessions										
		Ecosystem Workshops								
		Conceptual Modeling								
				Vital Signs Prioritization and Selection						
					Protocol Development and Monitoring Design					
								Phase 3 Report Peer Review		
				Phase 1 Oct. 2005		Phase 2 Oct. 2006		Phase 3 Dec. 2007		Final Phase 3 Oct. 2008

Capulin Volcano NM

understanding of ecological processes is enhanced, and as trends are detected, future issues will emerge (Roman and Barrett 1999). The monitoring plan should therefore be viewed as a working document, subject to periodic review and adjustments over time as our understanding improves and new issues and technological advances arise.

1.5 SUMMARY OF EXISTING MONITORING WITHIN AND SURROUNDING NETWORK PARKS

The Natural Resource Challenge (NRC) represents the first service-wide effort to fund long-term monitoring. While the Inventory and Monitoring program is an opportunity to establish new facets of an ecological monitoring program, it is important to also examine past and current monitoring conducted by parks and their neighbors. Doing so will allow us to build upon those efforts and gain the maximum amount of understanding of park natural resources. As monitoring is defined as the collection of repeated observations (Elzinga et al. 1998), SOPN park projects were only considered to be either past or existing monitoring if measurements were taken at the same locations on several occasions (Table 1.9). Each monitoring program is described in greater detail in Appendix Q of Perkins et al. (2005).

Table 1.9 Current and historic monitoring projects within the Southern Plains Network according to their level 3 vital signs category.

Park	Vital Sign Level III Category	Monitoring Project	Years Data Collected	Data in Database	Detailed Protocol Available	Data Analyzed	Project Oversight
ALFL	Fire and Fuel Dynamics	Effects of Large Wildfire	1998-2003	No	No	No	LAMR
BEOL	Vegetation Communities	Vegetation Transects	1993-Present	Yes	Yes	No	BEOL
	Mammals	White-Tailed Deer	Unknown-Present	Yes	Yes	No	Colorado Division of Wildlife
	T&E Species and Communities	Prairie Dog Town Extent	2000-Present	Yes	Yes	No	BEOL
	Invasive/Exotic Plants	Exotic Plants	2000-Present	Yes	No	No	BEOL
	Groundwater Dynamics	Water Table	2001-2003	Yes	Yes	No	BEOL
	Fire and Fuel Dynamics	Fire Plots	2002-Present	Yes	Yes	No	BEOL and Southern Plains Fire Cluster
CAVO	Insect Pests	Gypsy Moth	1999-Present	No	No	No	CAVO, US Forest Service
	Fire and Fuel Dynamics	Fire Effects	2004	Yes	Yes	Yes	Pueblo Fire Cluster
	Wet and Dry Deposition	NADP Site	1984-Present	Yes	Yes	Yes	NADP
	Grassland Vegetation	Woody Encroachment	1974-1979	No	Yes	No	Eastern New Mexico University
CHIC	Microorganisms	E. Coli	2000-Present	Yes	Yes	No	CHIC
	Surface Water Dynamics	Lake Level		Yes	Yes	No	USGS
	Groundwater Dynamics	Stream Flow		Yes	Yes	No	USGS
	Groundwater Dynamics	Spring Flow	Through 1990s, 2003 – Present	Yes	No	No	Park
	Water Chemistry	Water Quality	2001-Present	Yes	Yes	No	CHIC
	Weather and Climate	Weather	1978-Present	Yes	Yes	No	CHIC
	Fire and Fuel Dynamics	Fire Effects	1999-Present	Yes	Yes	No	Southern Plains Fire Cluster
	Mammals	Deer	1999-Present	Yes	Yes	Yes	CHIC
	Invasive / Exotic Animals	Fire Ants	1999-Present	Yes	Yes	Yes	CHIC
FOLS	No Monitoring Projects						
FOUN	Fire and Fuel Dynamics	Fire Effects	2002-Present	Yes	Yes	No	Fire Cluster
LAMR	Surface Water Dynamics	Reservoir Level	1965-Present	Yes	Yes	Yes	Bureau of Reclamation
	Surface Water Dynamics	Streamflow	1965-Present	Yes	Yes	Yes	USGS
	Water Chemistry	Water Quality	1965-Present	Yes	Yes	Yes	Texas Natural Resources Conservation Commission and USGS

Table 1.9 Current and historic monitoring projects within the Southern Plains Network according to their level 3 vital signs category (continued).

Park	Vital Sign Level III Category	Monitoring Project	Years Data Collected	Data in Database	Detailed Protocol Available	Data Analyzed	Project Oversight
LAMR	Birds	Christmas Bird Count	1971-Present	Yes	Yes	No	Audubon
	T&E Species and Communities	Bald Eagle Winter Survey	1994-Present	No	Yes	No	Audubon
	Mammals	Deer	2004-Present	Yes	Yes	No	Texas Parks and Wildlife, LAMR
	Fire and Fuel Dynamics	Fire Effects	1999-Present	Yes	Yes	No	Southern Plains Fire Cluster
	Microorganisms	E. Coli	1999-Present	No	Yes	Yes	LAMR, Canadian River Municipal Water Authority
	Fishes	Game Fish	1994-Present	Yes	Yes	No	Texas Parks and Wildlife
LYJO	Water Chemistry	Water Chemistry	1996-Present	Yes	Yes	No	Lower Colorado River Authority provides oversight
	Plant Diseases	Oak Wilt	2002-Present	No	No	No	Annual Survey with Texas Forest Service
	Weather and Climate	Weather Station	2002-Present	Yes	Yes	No	Texas Forest Service
PECO	Weather and Climate	Temperature and Precipitation	1989-Present	Yes	No	No	PECO
	Birds	Christmas Bird Count	2002-Present	Yes	Yes	No	Audubon
SAND	Surface Water Dynamics	Stream Flow	2003-Present	No	No	No	Town of Eads Public Works Division
WABA	No Monitoring Projects						

CHAPTER 2. CONCEPTUAL MODELS

"A thing is right when it tends to preserve the integrity, stability and beauty of the biotic community. It is wrong when it does otherwise"
- Aldo Leopold, A Sand County Almanac

2.1 INTRODUCTION AND BACKGROUND

2.1.1 SOPN Approach to Conceptual Model Development

A conceptual model is a visual or narrative summary that describes the important components of an ecosystem and the interactions among those components. Conceptual models show the interconnectedness of ecological processes, whether naturally occurring or anthropogenically driven. Conceptual models further help identify how major drivers and stressors will impact ecosystem components (Barber 1994). Most relevant to the Vital Signs Monitoring Program, conceptual models can help identify possible indicators for monitoring long-term ecosystem health. SOPN created conceptual diagrams individualized for each park to identify and show the major natural resource issues and stressors at each park. SOPN then used a combination of developing new models for SOPN specific ecosystems and concerns, and adapting models from other I+M networks where ecosystem types were similar.

2.1.2 Purpose of Conceptual Models

Conceptual models may be considered as "caricatures of nature" (Holling et al. 2002) or purposeful representations of reality (Starfield et al. 1994). They are designed to describe and communicate ideas about how nature works. Given the complexity of natural systems and the range of factors that influence natural processes, models provide a way to organize information. Conceptual models depicting key structural components, system drivers and their interactions assist us in thinking about the context and scope of the processes that effect ecological integrity (Karr 1991). They also provide a heuristic device to expand our consideration across traditional disciplinary boundaries (Allen and Hoekstra 1992), fostering interaction of biotic an abiotic information.

Conceptual models provide a mental picture of how something works. They can take a variety of forms—from narrative descriptions to schematic diagrams or flowcharts with boxes and arrows. Models generally work best when they include only the minimum amount of information needed to meet the model's purpose (Starfield 1997). Learning that accompanies the design, construction, and revision of models contributes to developing a shared perspective of system dynamics and our current level of understanding (Wright 2002). At all stages in the development of a monitoring program, conceptual models can improve communication between scientists from different disciplines, between scientists and managers, and between managers and the general public. Conceptual models should become everyday tools that are routinely used throughout the process of developing and implementing ecological monitoring.

Conceptual models help meet several key goals in the design and implementation of a monitoring program (Starfield and Bleloch 1986, Turner and O'Neill 1995, Gross 2003). First, early in the development of a monitoring program, they are communication tools that structure discussion and guide collection of background information (e.g., Wright 2002). Second, they aid in understanding the relevant structure and function of multiple levels of ecological organization that then allows inclusion of a system-wide perspective in the design of a monitoring program. Third, they allow explicit connection to management concerns by incorporating feedback between management actions and change in ecological attributes ("adaptive management"; sensu Holling 1978) into the structure and design of monitoring programs. Finally, they are key tools for selecting indicators or Vital Signs for use in long-term monitoring programs. Ecological monitoring programs often fail to formulate meaningful monitoring strategies. Conceptual models provide a framework for clarifying these strategies, enabling us to progress from general monitoring questions to more specific ones (Gross 2003).

2.1.3 Rationale for Conceptual Models

A premise of the SOPN vital-signs monitoring program is that the many species and landscapes valued by NPS staff, visitors, and society at large cannot be conserved in the absence of an ecosystem focus. This perspective is based on practical as well as theoretical considerations. Walker (1995:748) noted that "Given our inadequate understanding and knowledge of how many and which kinds of species occur in an ecosystem, the best way to

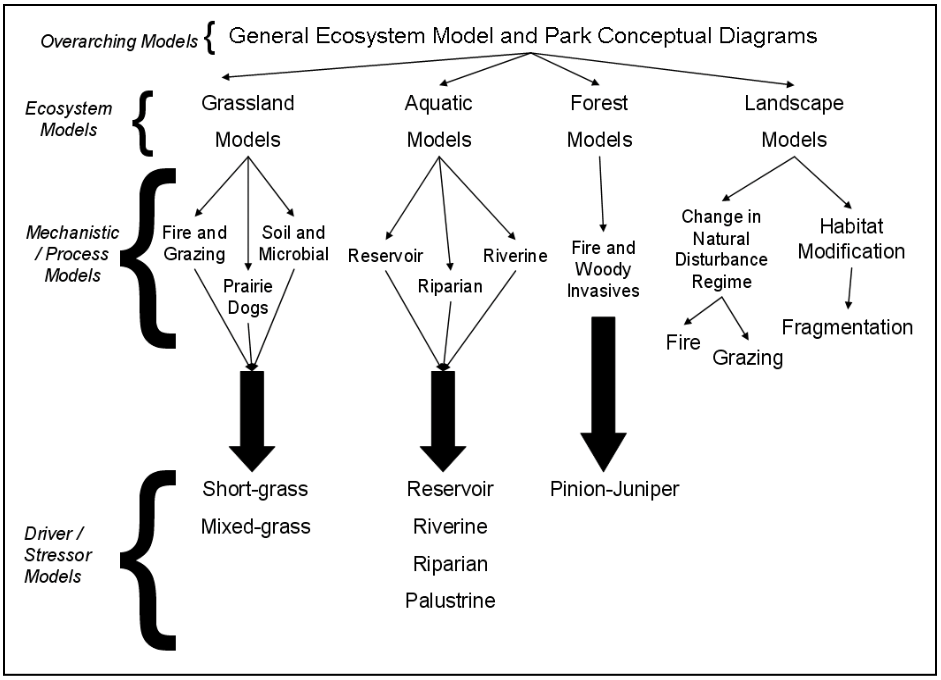

Figure 2.1 Diagram illustrating the hierarchical relationships of the Sothern Plains Network models

approach the problem of conserving them all is to ensure that the system continues to have the same overall structure and function"—a practical view shared by many conservation biologists (e.g., Noss 1990, Franklin 1993, Noon et al. 1999). Contemporary ecological theory further suggests that conservation should emphasize the maintenance of ecosystem processes because ecosystems and ecosystem components are inherently dynamic both in space and in time and thus cannot be conserved as static entities (Pickett et al. 1992, Christensen et al. 1996). The process-based perspective described for ecosystems is equally important to other levels of organization including populations, species, and landscapes. Ecosystems are connected with other ecosystems by flows of materials, energy, and organisms in spatially structured landscape mosaics (Turner et al. 2001). Thus landscape-level considerations are encompassed in the ecosystem approach of the SOPN.

2.1.4 Hierarchy of Conceptual Models

No single conceptual model can satisfy all needs. Spatially explicit applications such as ecological resource assessments, monitoring design (i.e., stratification), and landscape-level ecological modeling ultimately will require site-specific models, however generalized ecological models are useful to facilitate communication among scientists, managers, and the public regarding ecosystems and how they are affected by human activities and natural processes. An iterative process was used which first defined a general ecological model for the SOPN, and then developed ecosystem characterization models for broadly defined ecosystem types. SOPN will adapt and refine these models as information of site-specific data concerning abiotic constraints, local land-use history, current condition, and spatio-temporal ecosystem dynamics is gathered. While proximate efforts are focused on developing ecosystem characterization models, ecosystem dynamics models and completing accompanying literature reviews to form generalized representations of predominant Southern Plains ecosystems, our ultimate aim will be to customize these models describe local ecosystem dynamics.

Hierarchy theory provides a theoretical context for decomposing a complex system into a nested set of less complex submodels that span a range of spatial/temporal scales and ecological levels (O'Neill et al. 1986, Allen and Hoekstra 1992). Processes operating at much larger or smaller scales than the process of interest can usually be aggregated. In other words, processes operating at much larger scales act as constraints on the system, while those operating at much finer scales result in dynamics that occur so rapidly that they are perceived as static.

The model hierarchy (Figure 2.1) had customized individual park conceptual diagrams (Appendix R in Perkins et al. 2005) that emphasizes the major natural resources and stressors at each park (Figure 2.2 for an example) and a general ecosystem model that summarizes ideas about ecosystem sustainability at the top level. For each modeled ecosystem (grasslands, aquatic systems, forests and landscapes), there were generally three basic types of nested conceptual models (Figure 2.1). These are (1) general ecosystem characterization models, (2) ecosystem dynamics models, and (3) mechanistic models. Relatively detailed models are nested within more simple models. Ecosystem characterization models may be considered as generalized, highly aggregated models that describe the major system components, indicate the driving forces that control the system, and show the processes connecting ecosystem components. Ecosystem dynamics models present hypotheses concerning dynamics of selected components of the ecosystem. Mechanistic models provide details concerning the actual ecological processes responsible for patterns depicted in the dynamic models. For a given type of ecosystem, several dynamic submodels and mechanistic models may be required.

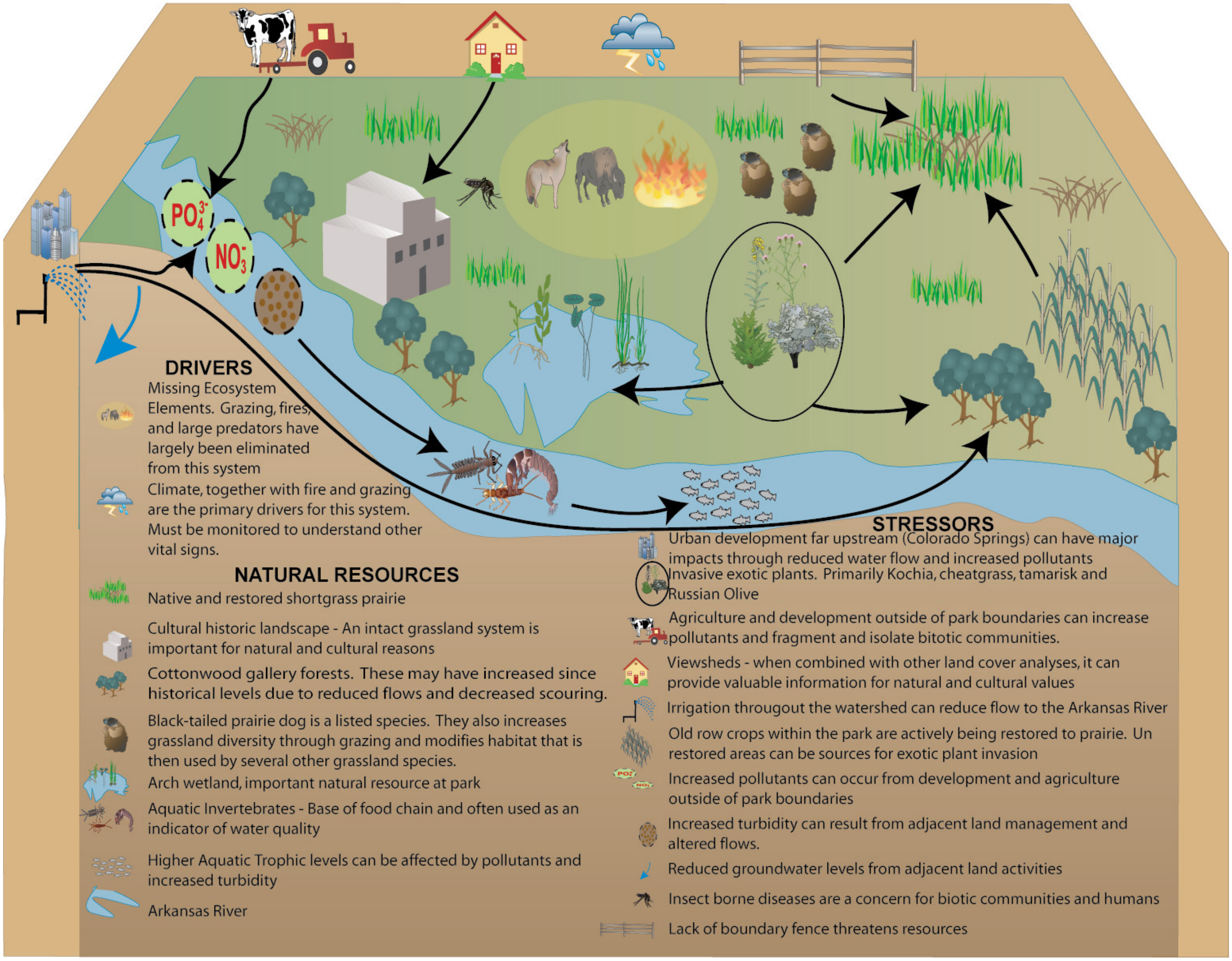

Figure 2.2 Example of a park conceptual diagram from Bent's Old Fort National Historic Site.

2.2 GENERAL ECOLOGICAL MODEL

For purposes of monitoring, it is useful to begin with a simple, general model that summarizes ideas about ecosystem sustainability. SOPN has adopted a modified version of the interactive-control model (Jenny 1941, Chapin et al. 1996) to serve as the general ecosystem model for SOPN conceptual model development (Figure 2.3). The Jenny-Chapin model defines state factors and interactive controls central to the functioning of sustainable ecosystems. This general model and a set of corollary hypotheses provide a theoretical foundation for aspects of the monitoring plan related to ecosystem structure and function.

Jenny (1941, 1980) proposed that soil and ecosystem processes are determined by five state factors: climate, organisms, relief (topography), parent material, and time since disturbance.

Jenny's state-factor approach has been widely applied as a framework for examining temporal and spatial variations in ecosystem structure and function (e.g., Walker and Chapin 1987, Vitousek 1994, Seastedt 2001). Chapin et al. (1996) recently extended this framework to develop a set of ecological principles concerning ecosystem sustainability. They defined "...a sustainable ecosystem as one that, over the normal cycle of disturbance events, maintains its characteristic diversity of major functional groups, productivity, and rates of biogeochemical cycling" (Chapin et al. 1996:1016). These ecosystem characteristics are determined by a set of four "interactive controls"–climate, soil-resource supply, major functional groups of organisms, and disturbance regime–and these interactive

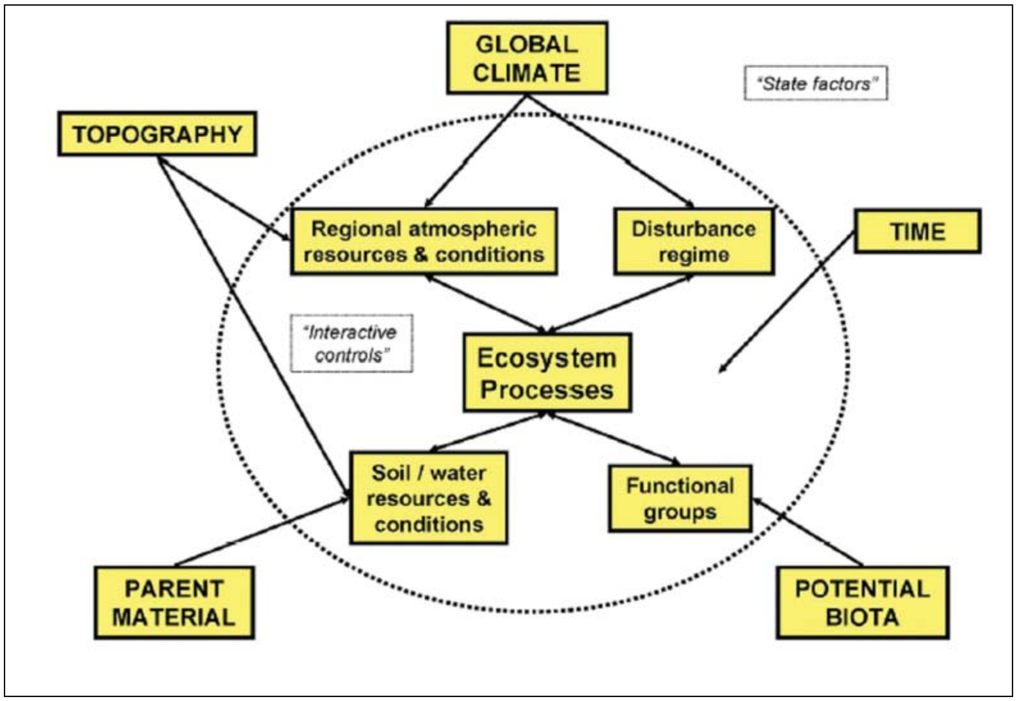

Figure 2.3 Aggregated system characterization model illustrating key ecosystem processes, characteristics and sustainability as a function of a hierarchical set of state factors and interactive controls. It may be used to "set the stage" for mode detailed, system-specific process and driver models. The circle represents the boundary of the ecosystem (from Chapin et al. 1996).

controls both govern and respond to ecosystem attributes (Figure 2.3). Interactive controls are constrained by the five state factors, which determine the "constraints of place" (Dale et al. 2000)

By substituting water quality and quantity for soil resources, the interactive-control model can be applied to aquatic as well as terrestrial ecosystems (Chapin et al. 1996). This extends the utility of the model, and suggests further clarifications. Soil, water, and air are the media from which primary producers acquire resources. As the abiotic matrix that supports the biota, they form the foundation of ecosystems. These media also are characterized by condition attributes (e.g., temperature, stability) that affect the physiological performance of organisms. Water and air qualities are accepted concepts with legislative standards. No legislative standards exist for the comparable concept of soil quality, and the concept itself was defined only recently. Karlen et al. (1997:6) defined soil quality as "the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation." Soil quality can be regarded as having two major components. First, an inherent component defined by the soil's inherent soil properties as determined by Jenny's (1941) five factors of soil formation. Second, there is a dynamic component defined by the change in soil function that is influenced by human management of the soil (Seybold et al. 1999). In terms of the interactive-control model, the concepts of water quality and soil quality will be used interchangeably with the more descriptive concepts of water resources and conditions and soil resources and conditions, respectively. With respect to climate as it is represented in the interactive-control model, the broader concept of atmospheric resources and conditions is more precise, encompassing climatic conditions such as temperature, resources such as precipitation and CO_2, and stressors such as airborne pollutants. This is an important clarification in the context of global environmental changes.

For vital signs monitoring, a key aspect of the Jenny-Chapin model is the associated hypothesis that interactive controls must be conserved for an ecosystem to be sustained. Large changes in any of the four interactive controls are predicted to result in a new ecosystem with different characteristics than the original system (Chapin et al. 1996, Vitousek 1994, Seastedt 2001). For example, major changes in soil resources (e.g., through erosion, salinization, fertilization, or other mechanisms) can greatly affect productivity, recruitment opportunities, and competitive relations of plants, and thus can result in major changes in the structure and function of plant communities and higher trophic levels. Changes in vegetation structure can affect the ecosystem's disturbance regime (e.g., through altered fuel characteristics). These factors and processes in combination can result in a fundamentally different type of ecosystem. Under some circumstances, effects of land uses such as grazing even can affect regional atmospheric resources and conditions through alterations of vegetation and soil conditions that alter ecosystem-atmosphere exchanges of water and energy (e.g., Bryant et al. 1990, Eastman et al. 2001). Additions or losses of species with traits that have strong effects on ecosystem processes also can result in an ecosystem with fundamentally different characteristics – potentially affecting the persistence of previous ecosystem components. Species that affect soil-resource regimes, disturbance regimes, or functional-group structure are those most likely to have profound effects on ecosystem characteristics following their introduction or loss from a system (Vitousek 1990, Chapin et al. 1997). Examples with particular relevance to vital signs monitoring include invasive exotic species that alter ecosystem disturbance regimes (D'Antonio and Vitousek 1992, Mack and D'Antonio 1998) and/or ecosystem resource regimes (Vitousek et al. 1987, Simons and Seastedt 1999).

2.3 MODEL TYPES

SOPN used a variety of model types for the different ecosystems within the network. An overview of the major types used is below.

2.3.1 Ecosystem Characterization Models

An ecosystem characterization model can be considered as a list of state variables and forcing functions of importance to the ecosystem and the problem in focus, but will also show how these components are connected by means of processes (Jorgensen 1986). The model provides a framework for hanging ideas and information from discussion and literature review. The components and organization of an ecosystem characterization model might look somewhat similar across a range of terrestrial or aquatic ecosystems, while the relative strength of system drivers and the nature of interactions between drivers and key components might vary from system to system. The objectives of ecosystem characterization models are:

1. to illustrate major subsystems and system components and their interactions;
2. to indicate the driving abiotic factors that constrain the system, depict their relationships to key structural components and processes, and describe resultant ecosystem characteristics;
3. to describe the predominant natural disturbances that historically influenced the system, indicate their relative importance in structuring the system, and summarize ecosystem-specific disturbance patterns (return intervals, extent, magnitude, seasonality);
4. to characterize the prevalent anthropogenic stressors that are currently affecting the system, describe their relationships to key structural components and processes, and describe resultant ecosystem effects.

One should be able to compare and contrast diagrammatic models for different systems and recognize important structural and functional similarities and differences between systems that have implications for monitoring. For example, cyclic or episodic drought may be a common overriding determinant of ecosystem dynamics in the Southern Plains and would be portrayed similarly across the models. In contrast, the relative importance of fire as a natural driver and the extent to which a legacy of fire suppression has altered vegetation structure varies widely across these ecosystems and should be characterized accordingly.

Work by Chapin et al. (1996) on ecosystem sustainability and Harwell et al. (1999) on ecosystem integrity together outline a framework for the categories of ecosystem components / attributes to be considered in ecosystem characterization models. With respect to biotic ecosystem components responsible for contributing to ecosystem sustainability, Chapin and colleagues emphasize a functional-group perspective. The concept of ecosystem integrity emphasizes the full range of biotic components, irrespective of functionality. Figure 2.4 is a diagrammatic example of an ecosystem characterization model for riverine systems.

2.3.2 Ecosystem Dynamics Models

Three of the five servicewide goals for vital-signs monitoring are oriented towards the dynamics of ecosystems or selected ecosystem components:

- Determine status and trends in selected indicators of the condition of park ecosystems to allow managers to make better-informed decisions and to work more effectively with other agencies and individuals for the benefit of park resources.
- Provide early warning of abnormal conditions of selected resources to help develop effective mitigation measures and reduce costs of management.
- Provide data to better understand the dynamic nature and condition of park ecosystems and to provide reference points for comparisons with other, altered environments.

It is clear from these goals that a fundamental purpose of vital signs monitoring is to detect meaningful changes in the condition (structure, functioning and composition) of park ecosystems. It is therefore essential that conceptual models developed to support vital-signs monitoring reflect the current state of knowledge regarding ecosystem dynamics – how and why ecosystems change as a consequence of interacting natural and human factors. Ecosystem-dynamics models thus represent the next level of detail in conceptual modeling required by the SOPN. The objectives for ecosystem dynamics models are:

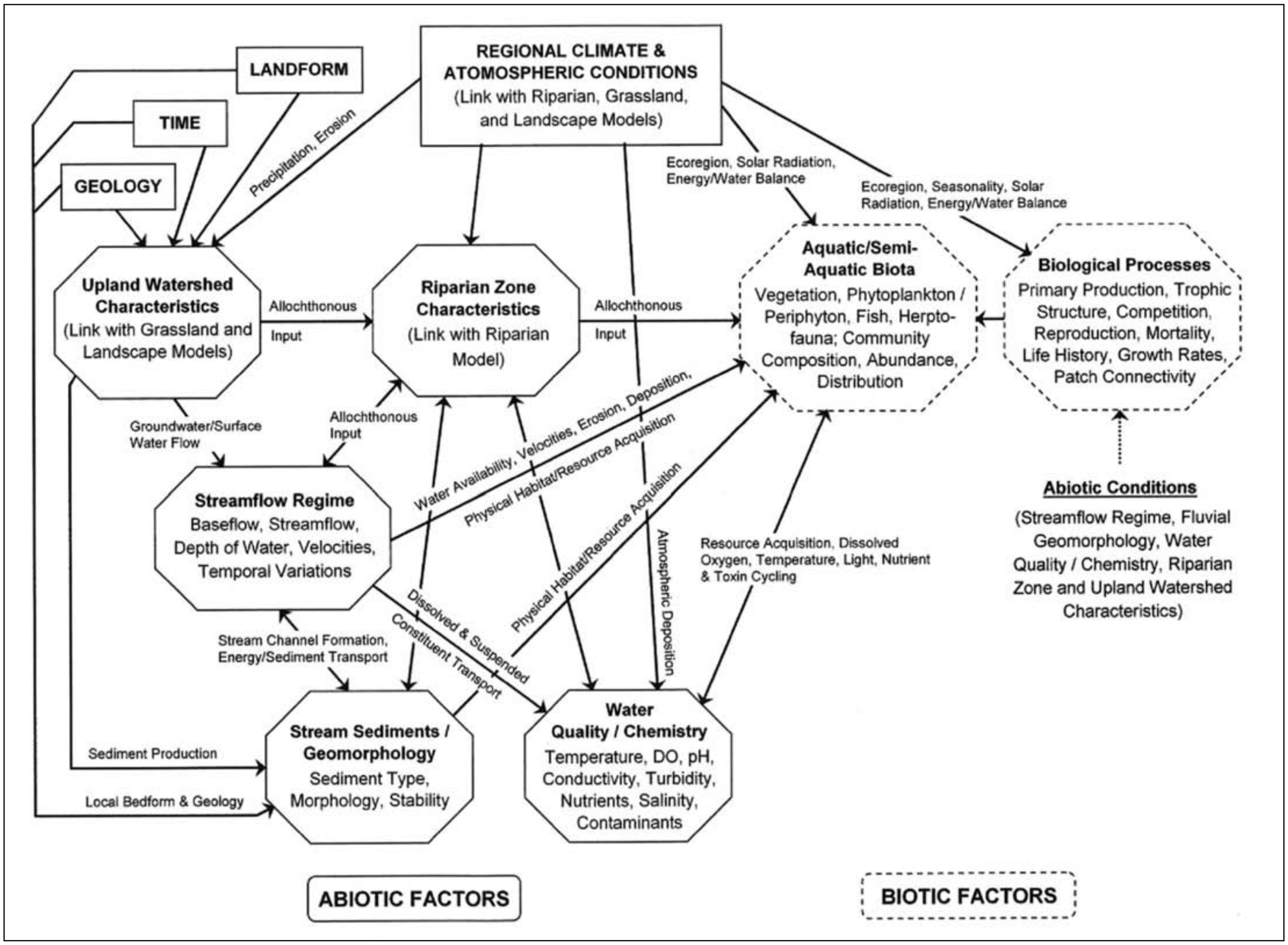

Figure 2.4 Example of an ecosystem characterization model for riverine systems. Rectangles indicate major drivers of ecosystem change and variability. Hexagons indicate major ecosystem components and processes (attributes). Arrows indicate ecosystem stresses and responses (functional relationships). The model is constrained by global climatic and atmospheric conditions, topography, parent (geologic) material and potential biota. Modified from Scott et al. (2005).

1. to identify the key components and interactions that historically controlled ecosystem structure and function
2. to describe ecosystem dynamics resulting from spatio-temporal variability in interactive controls
3. to illustrate key anthropogenic disruptions to system drivers
4. to provide a foundation for evaluating the range of current conditions of key structural components within the context of historic natural variability.

One difficulty in building models is determining which system components and interactions to include. Starfield et al. (1994) advises thinking of a conceptual model as a 'purposeful representation of reality', rather than as a comprehensive one. Allen and Hoekstra (1992) emphasize that "we do not wish to show that everything is connected, but rather to show which minimal number of connections that we can measure may be used as a surrogate for the whole system in a predictive model." Too much information can obscure critical components, while too little may lead to oversimplification (Margoulis and Salafsky 1998). Another important step in model construction is to identify an appropriate level of resolution, given the model objectives (Starfield and Bleloch 1986). Processes that occur much more slowly than the system of interest may be aggregated and considered as constraints of the system; processes that occur more rapidly than the system of interest may be aggregated and considered as 'noise' (Turner and O'Neill 1995). Figure 2.5 is an example of an ecosystem dynamics model for grasslands.

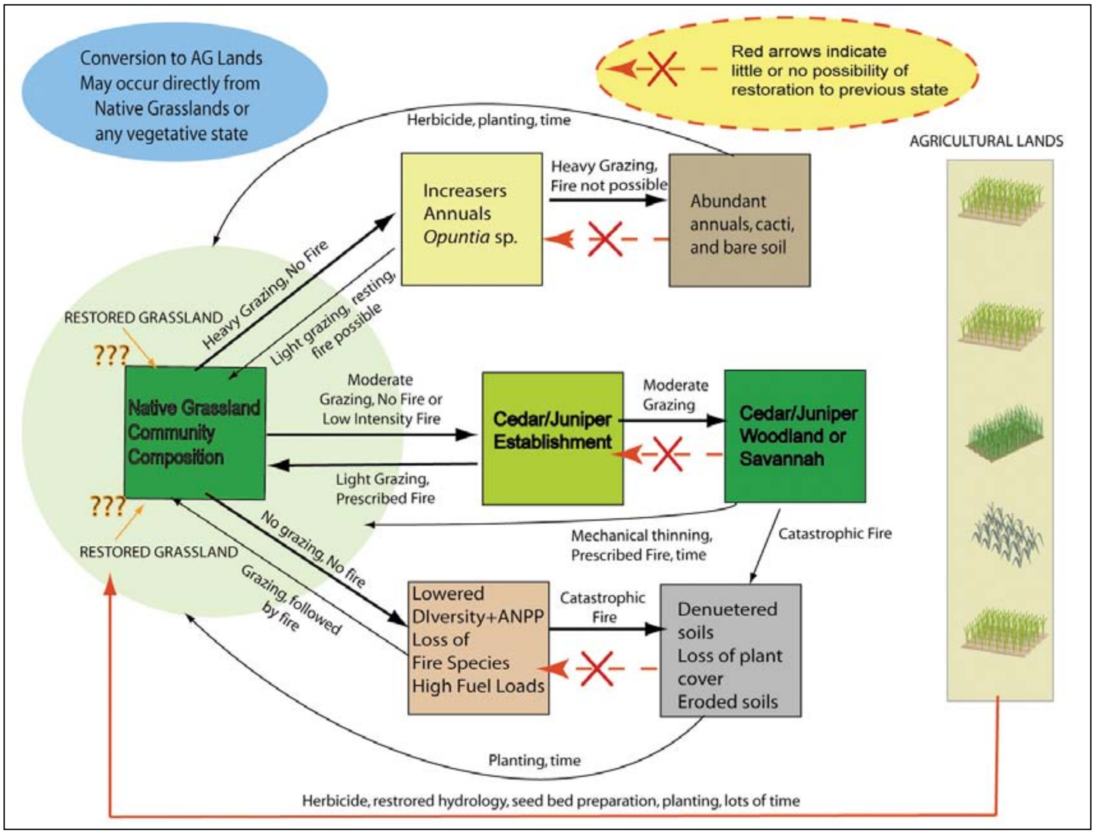

Figure 2.5 The Fire-Grazing submodel depicts three potential pathways for community composition changes that result from interactions of fire and grazing, as well as a fourth pathway that results in the conversion of any grassland community to agricultural lands.

frequently derived from control models, but they do not attempt a mechanistic representation of the system. Stressor models are likely to clearly communicate the direct linkages between stressors, ecological responses, and indicators. Figure 2.7 is an example of a stressor model for short-grass prairie ecosystems.

2.4 ECOSYSTEM SPECIFIC MODELS

The full model descriptions and diagrams are presented in Appendices S, T, U, V, and W in Perkins et al. (2005). Brief outlines of the models and submodels are presented here.

2.3.3 Mechanistic and Process Models

Mechanistic models provide details concerning the ecological processes responsible for patterns depicted in ecosystem dynamics models. Anticipatory indicators can be suggested by detailed mechanistic models that focus on processes leading to particular (undesirable) ecosystem transitions. They may also provide insight into pathways and primary or secondary effects of particular stressors (Figure 2.6). Mechanistic models should provide the necessary level of detail to suggest specific monitoring attributes or measures and to link them to the broader ecosystem context.

2.3.4 Stressor Models

Stressor models are designed to articulate the relationships between stressors, ecosystem components, effects, and (sometimes) indicators. Stressor models normally do not represent feedbacks and they include only a very selective subset of system components pertinent to a monitoring or other program. The intent of a stressor model is to illustrate sources of stress and the ecological responses of the system attributes of interest. These models are founded on known or hypothesized ecological relationships,

2.4.1 Grassland Models

Grassland models (Appendix S in Perkins et al. 2005) were developed by Dr. Dan Tinker and Dr. Ann Hild at the University of Wyoming. Grasslands are the most dominant ecosystem within SOPN parks. The grassland models begin with a pictorial diagram of the major processes and components for grassland systems in the Southern Plains Region. The next level of models were stressor models for short-grass and mixed-grass prairies. The major drivers for these systems are climate, fire, and grazing. An ecosystem dynamics model was then developed to show the potential pathways that can result from various levels of grazing and fire. Important components of grassland systems that are important to SOPN parks were then further developed in sub-models. These models were black-tailed prairie dogs and soil and microbial processes.

2.4.2 Aquatic Models

Aquatic ecosystems are second in importance only to grasslands in SOPN parks. While they take up a relatively small proportion of the landscape in the Great Plains region, they are often areas of high species diversity. Aquatic models were divided up into three types, rivers and streams (riverine), reservoirs (lacustrine), and prairie wetlands (palustrine). Riverine and lacustrine developed

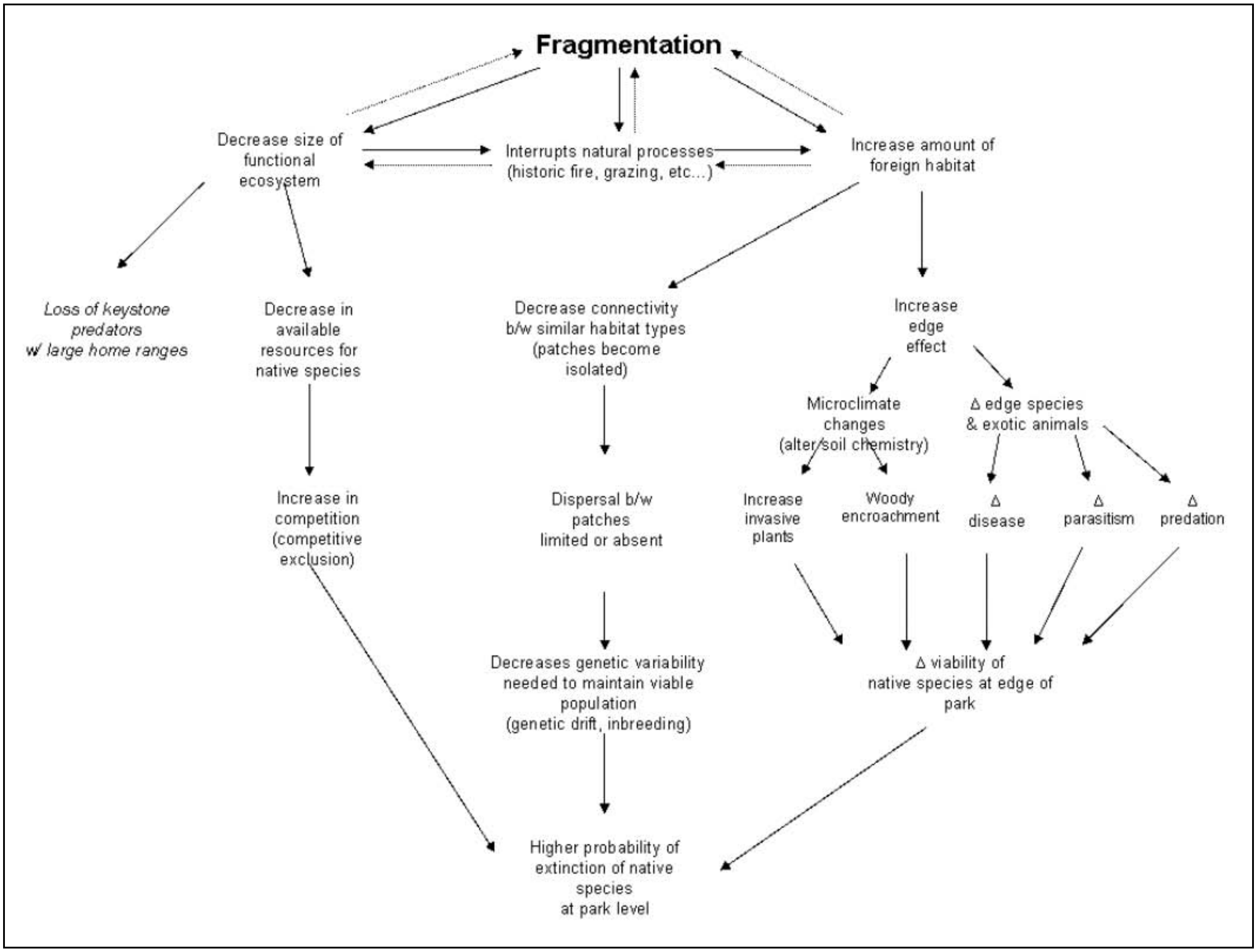

Figure 2.6 Example of a mechanistic model for fragmentation in Southern Plains Network parks.

by Sue Braumiller, Intermountain Regional Hydrologist (Appendix W in Perkins et al. 2005). The palustrine model was developed by the Heartlands network and adapted to fit SOPN by Dusty Perkins (Appendix V in Perkins et al. 2005).

Riverine models focus on the biotic components and three major abiotic components, streamflow regime, fluvial geomorphic processes, and water chemistry. Lacustrine models focus on the water sources, morphometry, mixing patterns, and trophic levels. Palustrine models focus on the natural hydrologic processes of drying and inundation, anthropogenic threats from development and agriculture, invasive species, and the alteration of the hydrologic regime.

2.4.3 Forest Models - Piñon-Juniper

Piñon-juniper forests are only present at two SOPN parks, yet they represent a dominant ecosystem at both of these parks (CAVO and PECO). Karie Cherwin of the University of Colorado developed forested models for these systems (Appendix U in Perkins et al. 2005). A stressor model and a mechanistic model that focuses on grazing and fire regimes and how they influence woody plant establishment were developed.

2.4.4 Landscape Vulnerability Models

SOPN developed landscape vulnerability models due to the small size of SOPN parks and their existence within a matrix of agriculture. Management and ecological processes that occur outside of the park often has more of an impact on park natural resources than management that takes place within park boundaries. The landscape models were developed by Todd Swannack at Texas A+M University (Appendix T in Perkins et al. 2005). The general landscape model identifies residential development, commercial development, agriculture, and management on neighboring land as the major landscape stressors.

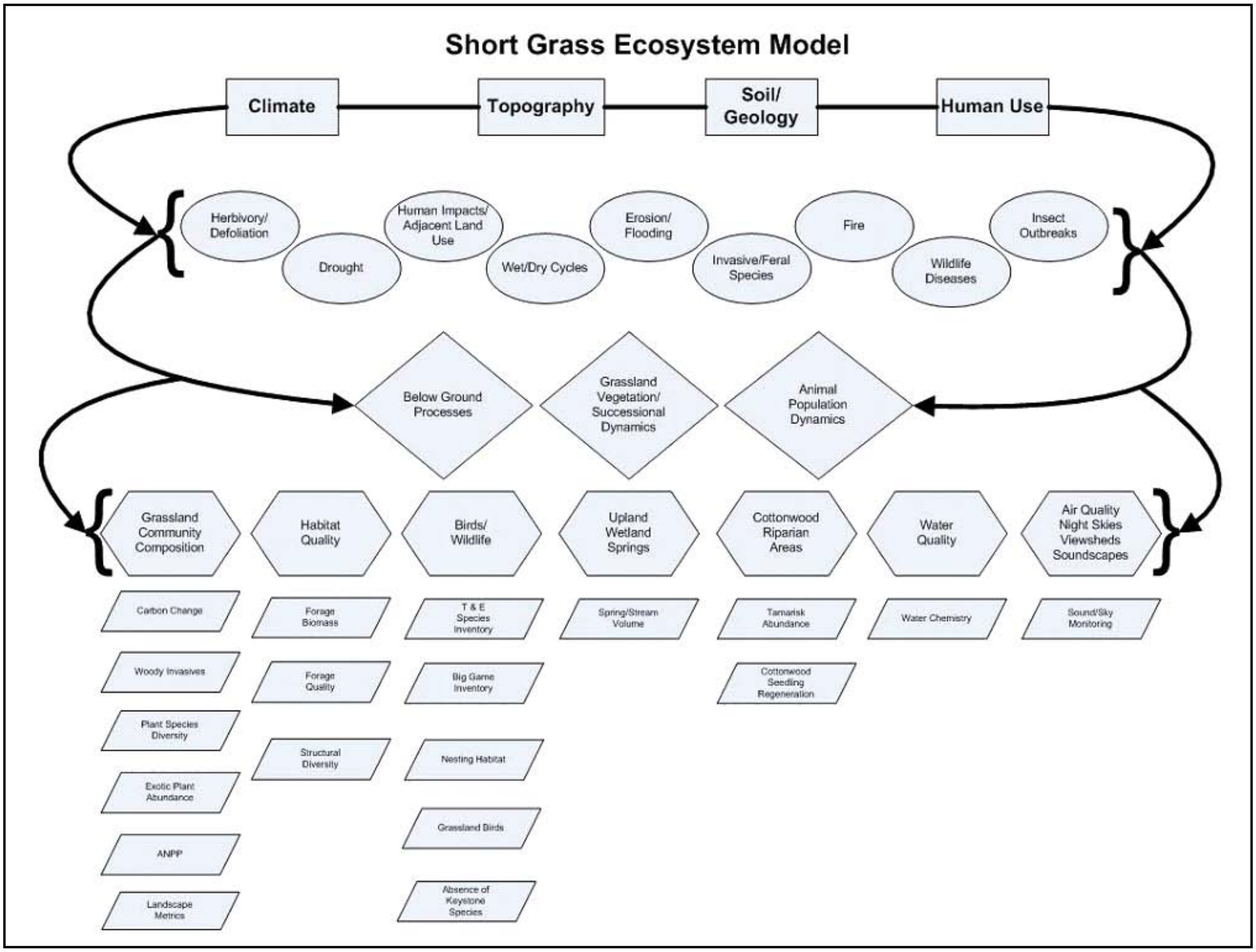

Figure 2.7 **Example of a stressor model. This model emphasize the drivers (boxes), stressors (ovals), ecological effects (diamonds), indicators (hexagons) and measurements (parrellogram).**

These stressors lead to a change in the natural disturbance regime and habitat modification, for which two submodels were developed. Nested underneath the change in natural disturbance regime were fire and grazing submodels. The major impacts of habitat modification were outlined in a fragmentation submodel.

2.5 SUMMARY

Conceptual modeling provides a valuable tool for identifying the important components of an ecosystem, the interactions among those components, how drivers and stressors impact the ecosystem, communication, and what measurements are possible for determining ecosystem health. Additionally, conceptual modeling provided these benefits:

- literature-based context for continued deliberations,
- multiple ecological frameworks as a basis for vital sign integration discussions,
- deliberate ecological assessment foundations with clear information legacy, and
- assessments of relevant spatial and temporal scales.

Importantly, the SOPN conceptual modeling efforts described revealed several potential vital signs that did not come up in park scoping sessions and helped to justify some potential high priority issues identified by park managers.

CHAPTER 3. VITAL SIGNS

"The prairie, in all its expressions, is a massive, subtle place, with a long history of contradiction and misunderstanding. But it is worth the effort at comprehension. It is, after all, at the center of our national identity."
- William Least Heat Moon (1991)

In this chapter, we describe the process used to prioritize and select the SOPN vital signs. The conceptual ecosystem models developed in Chapter 2 demonstrate that a variety of biological, chemical, and physical factors interact with plant and animal communities. Consequently, the overall condition or "health" of park ecosystems is determined by the interactions of these components. It is impossible to monitor all these components; and ecosystem condition cannot be measured directly. Therefore we identified vital signs that characterize entire park ecosystems, yet are simple enough to be effectively and efficiently monitored. The network developed a list of 29 selected vital signs through a multiple step process including scoping sessions, literature reviews, ecosystem workshops, a prioritization workshop, a selection meeting and finally a presentation to the Board of Directors (Figure 3.1).

3.1 OVERVIEW OF THE VITAL SIGNS SELECTION PROCESS

3.1.1 Identifying Potential Vital Signs

The process of selecting vital signs started in 2003 when SOPN began to develop a list of potential vital signs. This list was developed through scoping sessions with each SOPN park (see Section 1.3.1), reviewing peer reviewed and gray literature (Section 1.3.2), a preliminary resource issues and stressors survey (Section 1.3.3), conceptual model development (Chapter 2) and ecosystem workshops (Section 1.3.4). Conceptual ecosystem models and ecosystem workshops ensured that our list of potential vital signs had ecological relevance, particularly if the vital sign was a surrogate for the target process or resource. The park scoping sessions ensured that we were pursuing vital signs that were relevant to park issues and management decisions. This process resulted in a list of 93 potential vital signs that was presented in the Phase I Report (Perkins et al. 2005).

3.1.2 Prioritization of Vital Signs

SOPN staff revised and combined the 85 potential vital signs (Appendix J) from the Phase I Report into a list of 74 potential vital signs for further evaluation. Early in our process (April 20, 2005 Technical Committee Meeting), SOPN decided that the selected vital signs should focus on common issues across the network as opposed to a few high priority vital signs from each park. To accomplish this goal, SOPN developed a scoring system by reviewing existing scoring systems from other networks and discussions at 3 technical committee meetings. The scoring system was based on three criteria that were weighted as follows: management significance (40%), ecological significance (40%), and feasibility/cost of implementation (20%). Each criterion had between 5 and 8 statements that participants either agreed or disagreed with (Table 3.1). The score for each vital sign depended on how many statements the evaluator(s) agreed with. This system provided a consistent structure across evaluators and clearly articulated the basis for each score. Members of the technical committee led each park in ranking the potential vital signs according to management significance. We took the mean from all parks to generate one network management significance score for each vital sign (Appendix K, Table K.3) in keeping with our philosophy of selecting vital signs that are common for the whole network.

On January 24 and 25, 2005, SOPN held a workshop in Amarillo, Texas that was attended by a total of 44 people consisting of 31 subject matter experts from universities, non-profits, and government agencies, the technical committee, and SOPN staff (Appendix K, Table K.1). The goal of the workshop was to create a prioritized list of vital signs by combining the existing management significance scores with ecological significance and feasibility/cost of implementation scores created by workshop participants. The prioritization workshop was divided up into four workgroups: plants and soils, wildlife, aquatic resources, and landscape level issues. Each group had a facilitator that was familiar with the I+M program and the vital signs process (two were network coordinators, one was a former network coordinator, and one was a university ecologist that has helped SOPN and the Greater Yellowstone Network with the vital signs development process). Each workgroup reviewed a unique set of potential vital signs. The vital signs were all in an access database that had fields for potential monitoring questions, potential measures, and justification for each vital sign, which participants were encouraged to edit. When the same vital sign was reviewed by more then one group, the mean of the groups was taken. Six new vital signs were added to the original 74 vital signs that resulted in a prioritized list of 80 vital signs (Appendix K, Table K.6). Participants were also invited to make comments about merging or splitting vital signs.

The prioritized list was presented to the workshop participants. Vital signs that were rated in the top 25% were then given back to each workgroup for two final assignments. Each workgroup was asked if they felt there were any essential vital signs that were missing from the top 25% (Appendix K, page 136). Each work-group was also asked to brainstorm for potential existing protocols, existing monitoring programs, and potential partners for each one of the top vital signs.

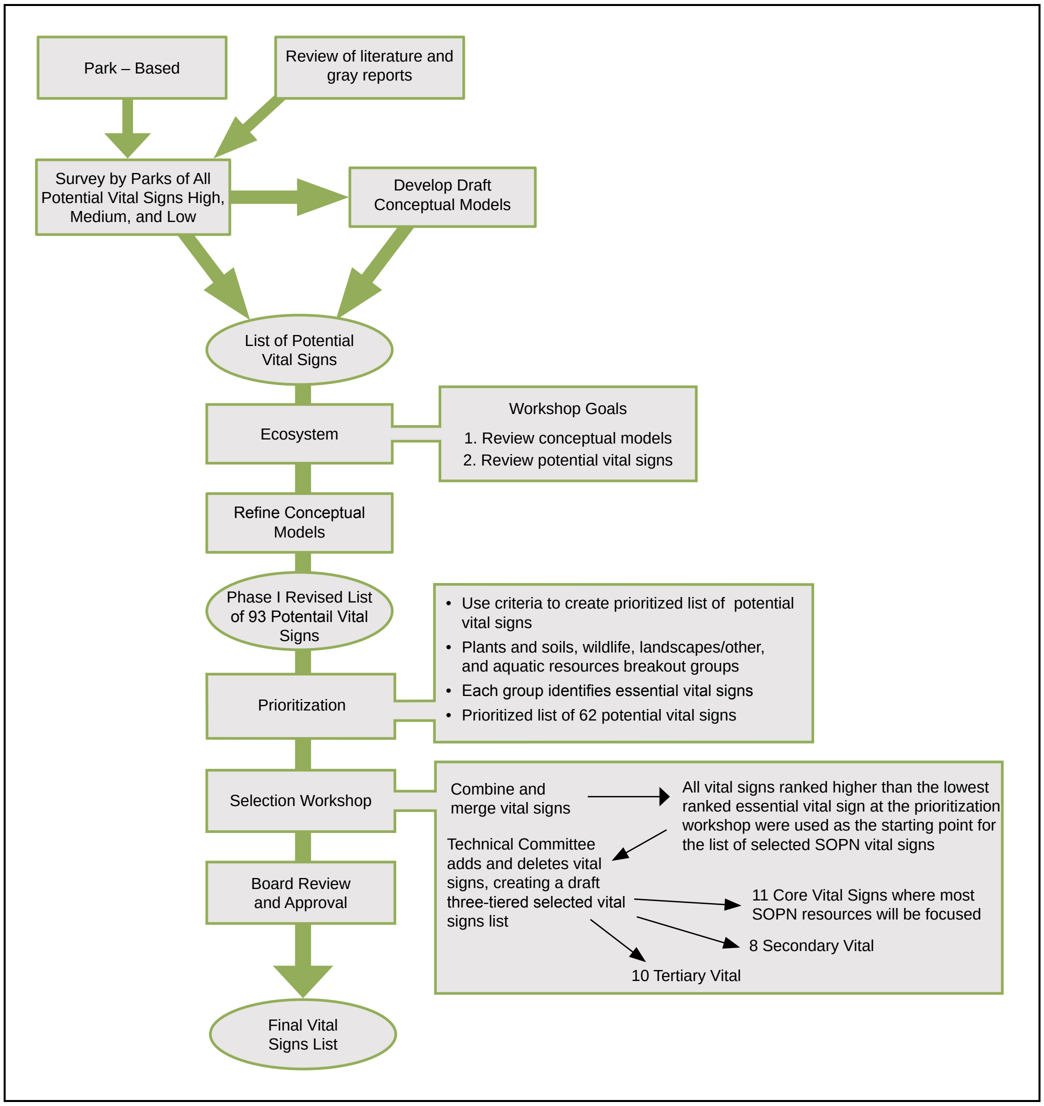

Figure 3.1 Vital signs selection process for the Southern Plains Network

3.1.3 Vital Signs Selection

The selection process concluded over two additional meetings. The first was a meeting of the SOPN Technical Committee that was held on January 26, 2005 in Amarillo, Texas to create a draft list of selected vital signs (Appendix L, Table L.2). The Technical Committee began by assigning a management significance ranking for the 6 new vital signs that were added during the prioritization workshop. The technical committee then approved or denied several suggestions from the prioritization workshop for merging vital signs, resulting in a new prioritized list of 62 potential vital signs (Appendix L, Table L.1). As a “straw man” selected vital signs list, we started with a list of 30 vital signs. This list represented everything that was prioritized above the lowest rated “essential” vital sign as determined by the four workgroups at the prioritization workshop. The group then deleted two vital signs from this list, merged two additional vital signs into one, and determined that no additional vital signs needed to be added. This resulted in a list of 28 selected vital signs that would be needed for a comprehensive network monitoring program. When our vital signs were placed into the vital signs framework, we split one vital sign into two. Our original water quantity vital sign was divided into surface water quantity levels and ground water levels. This resulted in a total of 29 vital signs (Table 3.2).

SOPN recognized that the current level of funding would not allow us to monitor all 29 vital signs, so the Technical Committee divided the selected vital signs into three tiers of 11 core, 8 secondary, and 10 tertiary vital signs. The network will first allocate resources to core vital signs, and these will likely make up the majority of the monitoring program in the near future. Secondary and tertiary vital signs will be considered for monitoring if additional funding is available, or if there are existing programs that make inclusion of these vital signs cost effective. The Technical

Table 3.1 Scoring statements used to rank Southern Plains Network vital signs according to three criteria.

Criteria	Scoring Statements
Management Significance (40%)	There is an obvious, direct application of the data to a key management decision, or for evaluating the effectiveness of past management decisions.
	Monitoring results are likely to provide early warning of resource impairment, and will save park resources and money if a problem is discovered early.
	The vital sign is of high importance to park natural resource management goals.
	Data are of high interest to the public.
	There is an obvious, direct application of the data to performance (GPRA) goals.
	Data are needed to give managers a better understanding of park resources so that they can make informed decisions. Contributes to increased understanding that ultimately leads to better management.
	Parks are required to monitor this resource by legal mandate or identification in major park planning document. Examples might include species that are federally listed as endangered or threatened, are in the park's enabling legislation, or are an issue/species that is a major management concern.
	In cases where data will be used primarily to influence external decisions, the decisions will affect key resources in the park, and there is a great potential for the park to influence the external decisions.
Ecological Significance (40%)	There is a strong, defensible linkage between the vital sign and the ecological function or critical resource it is intended to represent (supported by ecological literature or knowledge of system).
	The vital sign provides an early warning of changes to ecosystems or signifies an impending change in the ecological system. [Note: replace the term ecosystem with landscape or population, as appropriate.]
	The vital sign responds to change in a predictable and explainable matter.
	The vital sign has low natural variability (high signal to noise ratio).
	There are reference conditions that exist within the region and/or threshold values that could be determined to assess deviance from a natural condition.
	The vital sign reflects the capacity of key ecosystem processes to resist or recover from change induced by exposure to natural disturbances and/or anthropogenic stressors. [Note: replace the term ecosystem with landscape or population, as appropriate.]
	The vital sign represents a resource or function of high ecological importance based on the supporting ecological literature and knowledge of the system.
Cost of Implementation and Feasibility (20%)	The cost of monitoring the vital sign is not prohibitive. Consider all costs such as capital equipment, data collection, and analysis.
	The methods of monitoring for the vital sign are well established, repeatable, and are widely used and accepted.
	The vital sign is being monitored by other entities so that efficiencies can be realized in data acquisition, analysis, or other means.
	The methods of monitoring the vital sign are subject to limited human error, including errors due to different observers.
	The sampling will have limited negative impact on park resources.

Committee agreed unanimously on all 11 core vital signs. The vital signs in the secondary and tertiary categories were determined by a majority vote.

The second meeting took place on March 28, 2005, in Las Animas, Colorado. At this meeting SOPN presented the list of 29 selected vital signs (Table 3.2) to the Board of Directors for their review and approval. The Board approved the list unanimously, with the caveat that the costs of the 11 core vital signs will need to be determined during protocol development. There may be additional changes to the core vital signs list if the current level of funding cannot adequately address all of the current core vital signs.

3.2 SOUTHERN PLAINS SELECTED VITAL SIGNS

The SOPN has identified 29 vital signs that represent a systems approach to our monitoring program. Two vital signs relate to air and climate, 2 relate to geology and soils, 4 relate to water, 2 relate to human use, 2 relate to landscapes, and 17 relate to biological integrity. These vital signs appear in Table 3.2., presented in the hierarchical framework developed by the I+M Washington Office. In-depth summaries for each vital sign is provided in Appendix M. Our multi-faceted process resulted in a list of vital signs that is based on ecological and management significance, has been peer-reviewed, is justifiable, and is supported by conceptual ecosystem models.

Table 3.2 List of Southern Plains Network selected vital signs.

Level 1	Level 2	Level 3	Vital Sign	ALFL	BEOL	CAVO	CHIC	FOLS	FOUN	LAMR	LYJO	PECO	SAND	WABA
Air and Climate	Weather and Climate	Weather and Climate	Weather Patterns	●	●	●	●	●	●	●	●	●	●	●
	Air Quality	Wet and Dry Deposition	Wet and Dry Deposition	▼	▼	●	▼	▼	▼	▼	▼	▼	▼	▼
Geology and Soils	Soil Quality	Soil Function and Dynamics	Soil Structure and Chemistry	+	+	+	+	+	+	+	+	+	+	+
			Soil Movement	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼
Water	Hydrology	Ground Water Dynamics	Ground Water Levels	+	+	+	+●	+	+	+	+	+	+	+
		Surface Water Dynamics	Water Quantity	--	+	--	+●	+	--	+●	+	+	+●	+
			Flooding Processes	--	▼	--	▼	▼	--	▼	▼	▼	▼	▼
	Water Quality	Water Chemistry	Core Parameters (pH, dissolved oxygen, conductivity, temperature) and E. Coli	--	+	--	+●	+	--	+●	+●	+●	+	+
		Aquatic Macroinverte-brates and Algae	Aquatic Invetebrates	--	▼	--	▼	▼	--	▼	▼	▼	▼	▼
Biological Integrity	Invasive Species	Invasive / Exotic Plants	Early Detection Exotic Plants	+	+	+	+	+	+	+	+	+	+	+
		Invasive / Exotic Animals	Fire Ants	▼	▼	▼	●	▼	▼	▼	▼	▼	▼	▼
	Infestations and Diseases	Insect Pests	Insect Pests and Outbreaks	▼	▼	●	▼	▼	▼	▼	●	▼	▼	▼
		Plant Diseases	Plant Pathogens	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼
	Focal Species or Communities	Wetland Community	Wetland Vegetation Communities	--	+	--	+	+	--	+	+	+	+	+
			Upland Spring Communities	--	--	--	▼	--	--	▼	▼	▼	▼	--

\+ Core vital signs. SOPN will develop monitoring plans and protocols (are also shaded)
● Vital signs that are monitored by the park or another entity. These programs may or may not meet I+M standards
▼ Vital signs with no current or planned monitoring
-- Vital sign does not apply to that park

Table 3.2 List of Southern Plains Network selected vital signs (continued).

Level 1	Level 2	Level 3	Vital Sign	ALFL	BEOL	CAVO	CHIC	FOLS	FOUN	LAMR	LYJO	PECO	SAND	WABA
Biological Integrity	Focal Species or Communities	Grassland / Herbaceous Communities	Grassland Vegetation Communities	+	+●	+	+	+	+	+	+	+	+	+
		Terrestrial Invertebrates	Native Pollinators	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼
			Moths and Butterflies	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼
		Fishes	Fish Communities	--	▼	--	▼	▼	--	▼	▼	▼	▼	▼
		Amphibians and Reptiles	Amphibian Communities	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼
		Birds	Bird Communities	+	+	+	+	+	+	+	+	+	+	+
		Mammals	Ungulates	▼	●	▼	●	▼	▼	●	▼	▼	▼	▼
			Small Mammal Communities	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼
	At-Risk Biota	T&E Species and Communities	Black-tailed prairie dogs	--	●	--	--	▼	--	▼	--	--	▼	--
			Lesser Prairie Chicken	▼	--	--	--	--	--	▼	--	--	▼	--
Human Use	Non-Point Source Human Effects	Non-Point Source Human Effects	Human Demographics	+	+	+	+	+	+	+	+	+	+	+
	Visitor and Recreation Use	Visitor Use	Effects of Park Visitors on Natural Resources	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼
Landscapes	Fire and Fuel Dynamics	Fire and Fuel Dynamics	Fire and Fuel Dynamics	+	+●	+	+●	+	+●	+●	+	+	+	+
	Landscape Dynamics	Land Cover and Use	Landscape Dynamics	+	+	+	+	+	+	+	+	+	+	+

+ Core vital signs. SOPN will develop monitoring plans and protocols (are also shaded)
● Vital signs that are monitored by the park or another entity. These programs may or may not meet I+M standards
▼ Vital signs with no current or planned monitoring
-- Vital sign does not apply to that park

The final list of 29 vital signs represents a balance of ecosystem driving variables (drivers and stressors) and response variables (ecosystems, communities and species). The vital signs include the potential to monitor at different spatial and temporal scales and include some sensitive, "quick-response" indicators, as well as some slower, more integrative indicators.

SOPN will develop protocols for the 11 core vital signs according to preliminary monitoring objectives (Table 3.3). Preliminary monitoring objectives for secondary and tertiary vital signs are in Appendix M. Sampling designs will be devised for each park so that data collected will address the monitoring objectives. Monitoring objectives will likely be further refined during protocol development.

It is impossible for any monitoring program on a limited budget to develop a complete picture of ecosystem health with its staff and funding alone. Therefore, it is essential that the network integrate with ongoing monitoring programs to maximize the amount of information that is available to make informed management decisions. The network will work with the parks and potentially other entities to update and revise existing protocols to meet WASO I+M guidelines in order to synthesize and report on the state of the parks' ecosystems. In addition, the network will work with park staff to create models for database and information management, with the goal of increasing the usefulness of collected data.

An important challenge in designing a comprehensive monitoring program is the integration of different monitoring projects that provide information for the same, or similar, monitoring questions. In this fashion, the interpretation of the whole monitoring program yields information more useful than that of individual parts (Jenkins et al. 2002). We can optimize the utility of the monitoring program by early consideration of important relationships between vital signs and an evaluation of which monitoring objectives require integrated data collection and/or interpretation. Most monitoring has the potential to provide valuable information about multiple vital signs. During protocol development, we will analyze how the timing and location of monitoring projects can be integrated and pursued via partnerships to maximize the efficiency and the value of information collected.

Selected vital signs may be modified as fiscal resources and management issues change. Adjustments to the monitoring program may also occur as subsequent monitoring program reviews are conducted at approximately five year intervals. These reviews will provide feedback on the efficacy of the selected indicators (to be developed in Chapter 8 of Phase III Report). It may be discovered that it is necessary to expand the list of candidate vital signs to more completely describe natural resource status and trends, or to meet an expanded mandate for monitoring.

A preliminary task toward developing a framework for integrated monitoring is to define the spatial scales, and replication and measurement efforts (Jenkins et al. 2002) associated with particular vital signs. This will assist us in developing general sampling designs and assessing the relative cost and effort associated with particular vital signs. Spatial scale consists of two parts: extent, or the total area over which observations are made, and grain, the smallest interval of space measured (O'Neill and King 1998). Replication includes a spatial component (the number of independent sample plots) and a temporal component (the sampling frequency or number of samples through time). Measurement effort refers to the amount of information that is gathered at each sampling site, and may also include processing time (e.g., for remotely sensed data).

3.3 RELATIONSHIPS OF SELECTED VITAL SIGNS TO CONCEPTUAL MODELS

Our list of selected vital signs was a result of using both conceptual models to ascertain ecologically relevant vital signs and from discussions with park staff to develop vital signs that were important to park management. Before conceptual model development began, SOPN conducted sessions with each park to determine the biggest resources and stressors for each park (Appendix M in Perkins et al. 2005). We then gave these lists of resources and stressors to our model developers to be incorporated into the models. The model developers used their own extensive knowledge of the systems to add additional resources and stressors that were important at the ecosystem level. Many of these issues were ones that managers don't think of regularly because they often have little control of these issues. This two-pronged approach allowed us to select vital signs that were both relevant to park management and are significant to southern plains ecosystems.

Our conceptual models identified major components and processes of ecosystems in the SOPN. We developed over 32 different conceptual models in a hierarchical fashion. These models included general ecosystem models, park conceptual diagrams, and sub-models that focused on small portions of an ecosystem. However, the models did not attempt to quantify which resources and stressors were most important to SOPN across models. It is therefore reassuring that the vital signs that we have selected through the quantitative prioritized list (Appendix K) and the selection process (Appendix L) are all identified on our conceptual models (Appendices S-W in Perkins et al. 2005). All 11 core vital signs can be found on our

Table 3.3 Monitoring objectives for the 11 Southern Plains Network core vital signs.

Vital Sign	Monitoring Objective(s)
Soil Structure and Chemistry	1. Determine trends in annual soil respiration measurements 2. Detect changes in ecosystem carbon balance 3. Determine status and annual trends in soil cover, aggregate stability, compaction and erosion
Ground Water Levels	1. Determine the long-term trends in groundwater quantity levels. 2. Document changes in hydrologic regime associated with hydrological modifications (e.g., dams, diversions) in the SOPN
Water Quantity – Surface	1. Determine the long-term hydrologic trends for stream flow and lake water levels. 2. Document changes in hydrologic regime associated with hydrological modifications (e.g., dams, diversions) in the SOPN
Water Quality – Core Parameters	1. Determine the long-term trends in water quality vital signs at SOPN water bodies. 2. Determine trends in water chemistry in association with other network monitoring programs. 3. Determine fecal coliform levels and trends.
Exotic Plants	1. Detect incipient populations and new introductions of invasive exotic plant species.
Wetland Vegetation	1. Determine temporal and spatial trends in species composition and richness, abundance, structure, and diversity of wetland plant communities. 2. Quantify changes in the cover, richness, and species diversity of key woody native and non-native wetland trees within network parks. 3. Determine long-term trends in exotic plant abundance and distribution. 4. Compare long-term trends in areas where exotic plants are purposefully managed.
Grassland Vegetation	1. Define the trends in status of the vegetation species composition, structure, and diversity of remnant, disturbed, and restored prairies 2. Determine trends in cool season (C3) vegetation versus warm season (C4) vegetation. 3. Determine long-term trends in invasive woody species abundance and distribution. 4. Determine long-term trends in exotic plant abundance and distribution. 5. Compare long-term trends in areas where exotic plants and woody invasives are purposefully managed.
Bird Communities	1. Identify significant temporal changes in composition and abundance of bird communities at SOPN parks during the breeding season. 2. Improve our understanding of breeding bird – habitat relationships and the effects of management actions such as grazing and prescribed fire regimes on bird populations by correlating changes in bird community composition and abundance with changes in habitat variables.
Human Demographics	1. Detect trends in human demographic data in the vicinity of SOPN parks.
Fire and Fuel Dynamics	1. Track the location, extent, timing, and severity of wildland and prescribed fires in SOPN parks 2. Track successional effects of fire and burn severity on: the species composition and structure of vegetation; soil temperature and moisture; and animal community composition.
Landscape Dynamics	1. Determine variation and trends in the seasonally integrated normalized difference vegetation index (NDVI) for SOPN park lands. 2. Determine long-term trends in land-use change within and adjacent to SOPN parks.

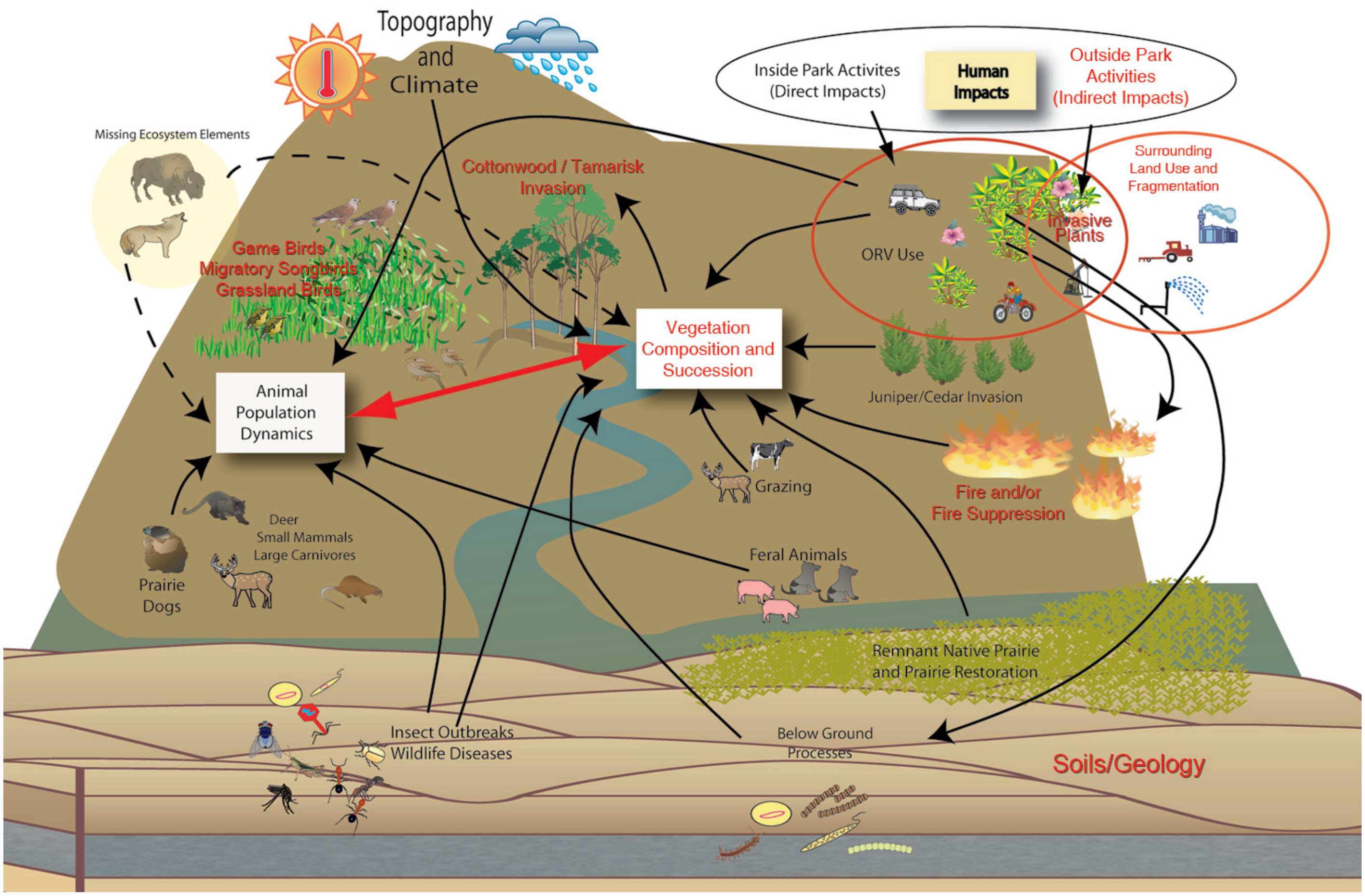

Figure 3.2 Overall grassland ecosystem model with core vital signs identified in red. The complete grassland conceptual model is in Appendix S of Perkins et al. (2005).

highest level ecosystem models for grassland (Figure 3.2) and stream (Figure 3.3) ecosystems. In addition many of our secondary and tertiary vital signs are also found on these two models.

A comprehensive monitoring program should have a mix of driver/stressor vital signs and ecological response vital signs. Driver/stressor vital signs are necessary because they allow managers to predict changes before they occur and make proactive management decisions. Ecological response vital signs tell a manager how the biological community is responding. For example, a conceptual model could be developed that demonstrates that cottonwood gallery forests with a certain density, width and age structure are ideal for bird communities. However, if the bird communities do not respond, the model is either not appropriate for the system or another unknown variable is preventing the predicted response in bird communities. As can be seen in our conceptual models, most of our core vital signs are stressor or driver oriented, only one – bird communities, is a true ecological response variable. A few of them, such as grassland vegetation, could be seen as a driver or an ecological response. With a limited budget, we think that monitoring the most important ecological drivers/stressors will give managers the most information. As we develop into a comprehensive monitoring program that monitors all 29 selected vital signs, we will add more ecological response variables with our secondary and tertiary vital signs.

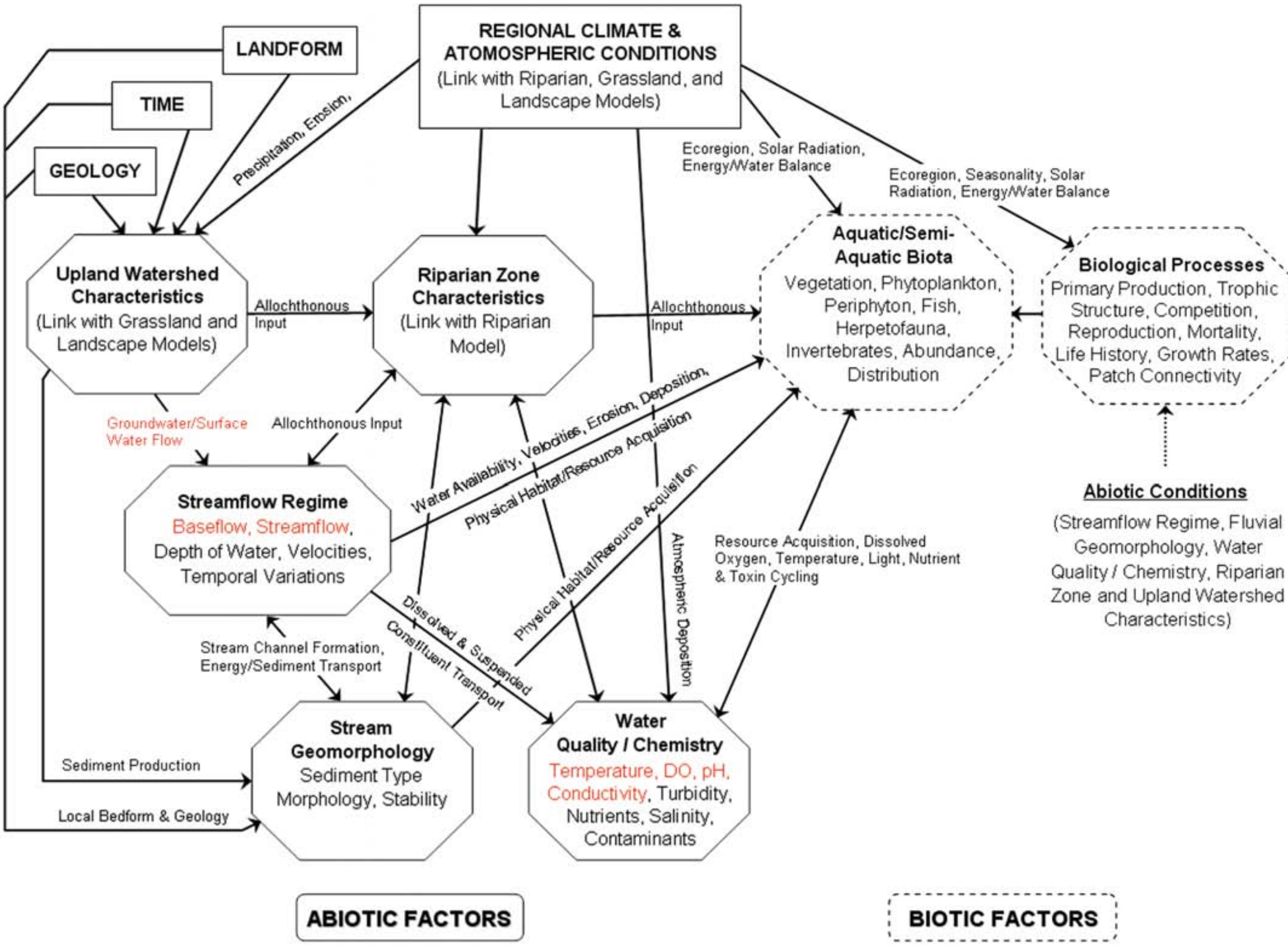

Figure 3.3 Overall stream ecosystem model with core vital signs identified in red. The complete stream conceptual model is in Appendix W of Perkins et al. (2005).

GLOSSARY OF TERMS USED BY THE INVENTORY AND MONITORING PROGRAM

Adaptive Management is a systematic process for continually improving management policies and practices by learning from the outcomes of operational programs. Its most effective form-"active" adaptive management-employs management programs that are designed to experimentally compare selected policies or practices, by implementing management actions explicitly designed to generate information useful for evaluating alternative hypotheses about the system being managed.

Attributes are any living or nonliving feature or process of the environment that can be measured or estimated and that provide insights into the state of the ecosystem. The term Indicator is reserved for a subset of attributes that is particularly information-rich in the sense that their values are somehow indicative of the quality, health, or integrity of the larger ecological system to which they belong (Noon 2003). See Indicator.

Ecological integrity is a concept that expresses the degree to which the physical, chemical, and biological components (including composition, structure, and process) of an ecosystem and their relationships are present, functioning, and capable of self-renewal. Ecological integrity implies the presence of appropriate species, populations and communities and the occurrence of ecological processes at appropriate rates and scales as well as the environmental conditions that support these taxa and processes.

Ecosystem is defined as, "a spatially explicit unit of the Earth that includes all of the organisms, along with all components of the abiotic environment within its boundaries" (Likens 1992).

Ecosystem drivers are major external driving forces such as climate, fire cycles, biological invasions, hydrologic cycles, and natural disturbance events (e.g., earthquakes, droughts, floods) that have large scale influences on natural systems.

Ecosystem management is the process of land-use decision making and land-management practice that takes into account the full suite of organisms and processes that characterize and comprise the ecosystem. It is based on the best understanding currently available as to how the ecosystem works. Ecosystem management includes a primary goal to sustain ecosystem structure and function, a recognition that ecosystems are spatially and temporally dynamic, and acceptance of the dictum that ecosystem function depends on ecosystem structure and diversity. The whole-system focus of ecosystem management implies coordinated land-use decisions.

Focal resources are park resources that, by virtue of their special protection, public appeal, or other management significance, have paramount importance for monitoring regardless of current threats or whether they would be monitored as an indication of ecosystem integrity. Focal resources might include ecological processes such as deposition rates of nitrates and sulfates in certain parks, or they may be a species that is harvested, endemic, alien, or has protected status.

Indicators are a subset of monitoring attributes that are particularly information-rich in the sense that their values are somehow indicative of the quality, health, or integrity of the larger ecological system to which they belong (Noon 2003). Indicators are a selected subset of the physical, chemical, and biological elements and processes of natural systems that are selected to represent the overall health or condition of the system.

Measures are the specific feature(s) used to quantify an indicator, as specified in a sampling protocol.

Stressors are physical, chemical, or biological perturbations to a system that are either (a) foreign to that system or (b) natural to the system but applied at an excessive [or deficient] level (Barrett et al. 1976:192). Stressors cause significant changes in the ecological components, patterns and processes in natural systems. Examples include water withdrawal, pesticide use, timber harvesting, traffic emissions, stream acidification, trampling, poaching, land-use change, and air pollution.

Vital Signs, as used by the National Park Service, are a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values. The elements and processes that are monitored are a subset of the total suite of natural resources that park managers are directed to preserve "unimpaired for future generations," including water, air, geological resources, plants and animals, and the various ecological, biological, and physical processes that act on those resources. Vital signs may occur at any level of organization including landscape, community, population, or genetic level, and may be compositional (referring to the variety of elements in the system), structural (referring to the organization or pattern of the system), or functional (referring to ecological processes).

LITERATURE CITED

Abrams, M.D. 1986. Historical development of gallery forests in northeast Kansas. Vegetatio. 65:29-37.

Agnew, W. D., W. Ursek, and R. M. Hansen. 1986. Flora and fauna associated with prairie dog colonies and adjacent ungrazed mixed-grass prairie in western South Dakota. Journal of Range Management 39:135-139.

Albertson, F. W. and G. W. Tomanek. 1965. Vegetation changes during a thirty-year period in grassland communities near Hayes, Kansas. Ecology 46:714-720.

Allen, T.F.H. and T.W. Hoekstra. 1992. Toward a unified ecology. Columbia University Press, New York, NY.

Anderson, R.C. 1982. An evolutionary model summarizing the roles of fire, climate and grazing animals in the origin and maintenance of grasslands. Pages 297-308 in J.R. Estes, R.J. Tyrl and J.N. Brunken, editors. Grasses and grasslands: systematics and ecology. University of Oklahoma Press, Norman..

Anderson, R.C. 1990. The historic role of fire in the North American grassland. Pages 8-18 in S.L. Collins and L.L. Wallace, eds. Fire in North American Tallgrass Prairies. University of Oklahoma Press, Norman, OK.

Archer, S., C. Scifres, C. R. Bassham, and R. Maggio. 1988. Autogenig succession in a subtropical savanna: conversion of grassland to thorn woodland. Ecological Monographs 52:111-127.

Archer, S., W. MacKay, J. Mott, S.E. Nicholsong, M. Pando Moreno, M.L. Rosenzweig, N.G. Seligman, N.E. West, and J. Williams. 1999. Arid and semiarid land community dynamics in a management context. In Arid lands management: Toward ecological sustainability, technical editing by T.W. Hoekstra and M. Shachak. University of Illinois Press, Urbana and Chicago.

Archer, S. 1989. Have southern Texas savannas been converted to woodlands in recent history? The American Naturalist. 134(4):545-561.

Axelrod, D.I. 1985. Rise of the grassland biome, central North America. Botanical Review 51: 163-202.

Bailey, R.G. 1994. Ecological classification for the United States. Washington, DC: USDA Forest Service.

Bailey, R. G. 1995. Description of the ecoregions of the United States, 2nd edition revised and expanded. Misc. Publ. 1391, U.S. Department of Agriculture Forest Service: Washington, D.C. 108 pp. + map.

Bakker, J. P., and J. C. Ruyter. 1981. Effects of five years of grazing on a salt-water marsh. Vegetatio 44:81-100.

Barber, M. C., editor. 1994. Environmental monitoring and assessment program indicator development strategy. EPA/620/R-94/022. Athens, Georgia: Environmental Protection Agency, Office of Research and Development, Environmental Research Laboratory.

Barrett, W. G., G. M. VanDyne, and E. P. Odum. 1976. Stress ecology. BioScience 26:192-194.

Benedict, R. A., P. W. Freeman, and H. H. Genoways. 1996. Prairie legacies – mammals. Pp. 149-167 in F. B. Samson and F. L Knopf (eds.). Prairie conservation: preserving North America's most endangered ecosystem. Island Press, Covelo, California, USA.

Bergey, E.A. 2003. Aquatic invertebrates and fishes of the Washita River in the Washita Battlefield National Historic Site. Oklahoma Biological Survey. Project 125-5967.

Biondini, M. E. A.A. Steuter and C.E. Grygiel. 1989. Seasonal fire effects on the diversity patterns, spatial distribution, and community structure of forbs in the northern mixed prairie. Vegetatio 85:21-31.

Black, C. C. 1971. Ecological implications of dividing plants into groups with distinct photosynthetic production capacities. Advances in Ecological Research 7:87-114.

Blake, A. K. 1935. Viability and germination of seeds and early life history of prairie plants. Ecological Monographs 5:405-460.

Bock, J. H., and C. E. Bock. 1995. The challenges of grassland conservation. Pages 199-222 in Joern, A., and K. H. Keeler, editors. The changing prairie: North American Grasslands. Oxford U. Press, New York. 244pp.

Bonner, T. H. and Wilde, G. R. 2000. Changes in the Canadian River fish assemblage associated with reservoir construction. Journal of Freshwater Ecology. 15(2):189-198.

Bragg, T. B. 1995. Physical Environment of Great Plains Grasslands. Grassland Ecology. Oxford University Press. pp. 49-81.

Bragg, T. B., and A. A. Stueter. 1996. Mixed-grass prairies of the North American Great Plains. Pages 53-66 *in* F. B. Samson and F. L. Knopf, editors. Prairie conservation preserving North America's Cook, R. R., J. E. Cartron, and P. J. Plocheta, Jr. 2003. The importance of prairie dogs to nesting ferruginous hawks in grassland ecosystems. Wildlife Society Bulletin 31:1073-1082.

Bramblett, R. G., and K. D. Fausch. 1991a. Fishes, macroinvertebrates and aquatic habitats of the Purgatoire River in Piñon Canyon, Colorado. Southwestern Naturalist. 36:281-294.

Bramblett, R. G., and K. D. Fausch. 1991b. Variable fish communities and the index of biotic integrity in a western Great Plains river. Transactions of the American Fish Society. 120:752-769.

Bragg, T. B., and A. A. Steuter. 1996. Mixed-grass prairies of the North American Great Plains. Pages 53-66 in F. B. Samson and F. L. Knopf, editors. Prairie conservation: preserving North America's most endangered ecosystem. Island Press, Covelo, Calif.

Brennan, L.A., and Kuvlesky, W.P.J. 2005. North American grassland birds: an unfolding conservation crisis? Journal of Wildlife Management 69: 1-13.

Breshears, D. D. and F. J. Barnes. 1999. Interrelationships between plant functional types and soil moisture heterogeneity for semiarid landscapes within the grassland/forest continuum: a unified conceptual model. Landscape Ecology 14:465-478.

Bryant, N. A.., L. F. Johnson, A. J. Brazel, R. C. Balling, C. F. Hutchinson, and L. R. Beck. 1990. Measuring the effect of overgrazing in the Sonoran Desert. Climatic Change 17:243-264.

Brockway, D., R. Gatewood, and R. Paris. 2002. Restoring fire as an ecological process in shortgrass prairie ecosystems: initial effects of prescribed burning during the dormant and growing seasons. Journal of Environmental Management 65:135-152.

Bryson, R. A. and F. K. Hare (eds.). 1974. World survey of climatology. Volume 11, Climates of North America. Elsevier Scientific Publishing, New York, New York, USA.

Butler, J. L. and D. D. Briske. 1988. Population structure and tiller demography of the bunchgrass Schizachyrium scoparium: interclonal versus intraclonal interference. Journal Ecology 77:963-974.

Callenbach, E. 1996. Bring back the buffalo!: a sustainable future for America's Great Plains. Island Press, Washington D.C. 280pp.

Catchpole, F. B. 1996. The dunamics of bison (*Bos bison*) grazing patches in tallgrass prairie. Master's Thesis. Kansas State University, Manhattan, Kansas.

Chapin, F. S., III, M. S. Torn, and M. Tateno. 1996. Principles of ecosystem sustainability. TheAmerican Naturalist 148: 1016-1037.

Chapin, F. S., III, B. H. Walker, R. J. Hobbs, D. U. Hooper, J. H. Lawton, O. E. Sala, and D.Tilman. 1997. Biotic control over the functioning of ecosystems. Science 277: 500-504.

Christensen, N. L., A. M. Bartuska, J. H. Brown, S. Carpenter, C. M. D'Antonio, R. Francis, J. F. Franklin, J. A. MacMahon, R. F. Noss, D. J. Parsons, C. H. Peterson, M. G. Turner, and R. G. Woodmansee. 1996. The report of the Ecological Society of America Committee on the scientific basis for ecosystem management. Ecological Applications 6: 665-691.

Cid, M. S., J. K. Detling, A. D. Whicker, and M. A. Brizuela. 1991. Vegetational responses of a mixed-grass prairie site following exclusion of prairie dogs and bison. Journal of Range Management 44:100-105.

Clark, J.S., E. C. Grimm, J. J. Donovan, S. C. Fritz, D. R. Engstrom, and J. E. Almendinger. 2002. Drought cycles and landscape responses to past aridity on prairies of the Northern Great Plains. Ecology 83(3):595-601.

Coffin, D. P. and W. K. Lauenroth. 1989. Spatial and temporal variation in the seed bank of a semi-arid grassland. American Journal of Botany 76:53-58.

Collins, S.L. and L.L. Wallace, eds. 1990. Fire in North American Tallgrass Prairies. University of Oklahoma Press, Norman, OK.

Collins, S. L., and S. M. Glenn. 1995. Grassland ecosystem and landscape dynamics. Pages 128-156 in Joern, A., and K. H. Keeler, editors. The changing prairie: North American Grasslands. Oxford U. Press, New York. 244pp.

Collins, S. L. and S. C. Barber. 1985. Effects of disturbance on diversity in mixed-grass prairie. Vegetation 64:87-94.

Coppedge, B.R., and J. H. Shaw. 1998. Bison grazing patterns on seasonally burned tallgrass prairie. Journal of Range Management, 51, 258–264.

Coppedge, B.R., D. M. Engle, C. S. Toepfer, and J. H. Shaw. 1998. Effects of seasonal fire, bison grazing and climatic variation on tallgrass prairie vegetation. Plant Ecology.139:235–246.

Coppock, D. L. and J. K. Detling. 1986. Alteration of bison/prairie dog grazing interaction by prescribed burning. Journal of Wildlife Management. 50:452-455.

Coppock, D. L., J. K. Detling, J. E. Ellis, and M. I. Dyer. 1983a. Plant-herbivore interactions in a North American mixed-grass prairie. II. Responses of bison to modification of vegetation by prairie dogs. Oecologia 56:10-15.

Coppock, D. L., J. K. Detling, J. E. Ellis, and M. I. Dyer. 1983b. Plant-herbivore interactions in a North American mixed-grass prairie. I. Effects of black-tailed prairie dogs on inter-seasonal aboveground plant biomass and nutrient dynamics and plant species diversity. Oecologia 56:1-9.

Cook, R. R.; J. E. Cartron, and P. J. Polechla Jr. 2003. The importance of prairie dogs to nesting ferruginous hawks in grassland ecosystems. Wildlife Society Bulletin. 31(4):1073-1082.

Costello, D. F. 1944. Natural revegetation of abandoned plowed land in the mixed prairie association of northeastern Colorado. Ecology 25:312-326.

Costello, D. F. 1969. The Prairie World. Crowell, New York.

Coupland, R. T. 1961. A reconsideration of grassland classification in the North American great Plains of North America. Journal of Ecology 49:135-167.

Cowardin, L. M., V. Carter, F. C. Golet, and E. T. LaRoe. 1979. Classification of wetlands anddeepwater habitats of the United States. U.S. Fish and Wildlife Service. FWS/OBS-79/31.

Cross, F. B., R. E. Moss, and J. T. Collins. 1985. Assessment of dewatering impacts on stream fisheries in the Arkansas and Cimarron rivers. Report to Kansas Department of Wildlife and Parks, Contract No. 46, Pratt, KS.

Cross, F. B., and R. E. Moss. 1987. Historic changes in fish communities and aquatic habitats in plains streams of Kansas. Pp. 155-165 in W. J. Matthews and D. C Heins, eds. Communitiy and evolutionary ecology of North American stream fishes. University of Oklahoma Press, Norman.

Croze, H. 1982. Monitoring within and outside protected areas. Pages 628-633 in J. A. McNeely and K. R. Miller, editors. National Parks, conservation, and development: The role of protected areas in sustaining society. Proceedings of the World Congress on National Parks, October 11-22,1982, Bali, Indonesia. Smithsonian Institution Press. Washington, D.C.

Dale, V. H., S. Brown, R. A. Haeuber, N. T. Hobbs, N. Huntly, R. J. Naiman, W. E. Riebsame, M. G. Turner, and T. J. Valone. 2000. Ecological principles and guidelines for managing the use of land. Ecological Applications 10: 639-670.

Dahl, T.E. 2000. Status and trends of wetlands in the conterminous United States 1986 to 1997. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C. 82 pp.

D'Antonio, C. M., and P. M. Vitousek. 1992. Biological invasions by exotic grasses, the grass/firecycle, and global change. Annual Review of Ecology and Systematics 23:63-87.

Daubenmire, R. 1968. Ecology of fire in grasslands. Advances in Ecological Research 5:209-266.

Davis, G.E. 1989. Design of a long-term ecological monitoring program for Channel Islands National Park, California. Natural Areas Journal 9(2):80-89.

Davis, M. A., J. Villinnski, K. Banks, J. Buckman-Fifield, J. Dicus, and S. Hofmann. 1991a. Combined effects of fire, mound-building by pocket gophers, root loss and plant size on growth and reproduction in *Penstemon grandifloris*. American Midland Naturalist 125:150-161.

Davis, M. A., J. Villinski, S. McAndrew, H. Scholtz, and E. Young. 1991b. Survivorship of *Penstemon grandifloris* in an oak woodland: combined effects of fire and pocket gophers. Oecologia 86:113-118.

Davenport, D. W., D. D. Breshears, B. P. Wilcox, and C. D. Allen. 1998. Viewpoint –sustainability of pinyon-juniper ecosystems: a unifying perspective on soils erosion thresholds. Journal of Range Management 51:229-238.

Day, T. A. and J. K. Detling. 1990. Grassland patch dynamics and herbivore grazing preference following urine deposition. Ecology 63:180-188.

De Leo, G. A., and S. Levin. 1997. The multifaceted aspects of ecosystem integrity. Conservation Ecology 1:3. Online.(http://www.ecologyandsociety.org/vol1/iss1/art3/). Accessed 28 September 2004.

Desmond, M. J., J. A. Savidge, and T. F. Seibert. 1995. Spatial patterns of burrowing owl (*Speotyto cunicularia*) nests within black-tailed prairie dog (*Cynomys ludovicianus*) towns. Canadian Journal of Zoology 73:1375-1379.

Dugan, J. T., T. McGrath, and R. B. Zelt. 1994. Water-level changes in the High Plains aquifer predevelopment to 1992. U.S. Geological Survey Water-Resources Investigations Report 94-4027. 34 pp.

Dyer, M. I., J. K. Detling, D. C. Coleman, and D. W. Hilbert. 1982. The role of herbivores in grassland. Pp. 225-261 in J. R. Estes, R. J. tyrl, and J. N. Bunken (eds.). Grasses and Grasslands. University of Oklahoma Press, Norman, Oklahoma, USA.

Eastman, J. L., M. B. Coughenour, and R. A. Pielke. 2001. Does grazing affect regional climate? Journal of Hydrometeorology 2:243-253.

Elzinga, C. L., D. W. Salzer, and J. W. Willoughby. 1998. Measuring and Monitoring Plant Populations. Bureau of Land Management Technical Reference 1730-1.

Eschner, T. R., R. F. Hadley, and K. D. Crowley. 1983. Hydrologic and morphologic changes in channels of the Platte River basin in Colorado, Wyoming, and Nebraska: a historical perspective. Geological Survey Professional Paper 1277-A, Washington DC.

Evans, K. E. and G. E. Probasco. 1977. Wildlife of the prairies and plains. General Technical Report NC-29. U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station, St. Paul, Minnesota.

Fahnestock, J. T. and A. K. Knapp. 1993. Water relations and growth of tallgrass prairie forbs in response to selective grass herbivory and water stress. International Journal of Plant Science 154:123-131.

Fahnestock, J. T. and A. K. Knapp. 1994. Plant responses to selective grazing by bison: interactions between light, herbivory and water stress. Vegetation 115:123-131.

Fausch, K. D. and K. R. Bestgen. 1997. Ecology of fishes indigenous to the central and southwestern Great Plains. Knopf, F. L. and Samson, F. B., Editors. Ecology and conservation of Great Plains vertebrates. New York: Springer; 1997; pp. 131-166.

Fausch, K. D. and R. G. Bramblett. 1991. Disturbance and fish communities in intermittent tributaries of a western Great Plains river. Copeia. 1991:659-674.

Flug, M. 1998. Ecosystem Resource Considerations in Reservoir Management: Water Resources Update: Universities Council on Water Resources. 43-56.

Foran, B.D. & G. Bastin. 1984. The dynamics of Mitchell grass rangeland on the Barkly tableland, Northern Territory. Australian Rangeland Journal, 6, 92–97.

Forrest, S. C., H. Strand, W.H. Haskins, C. Freese, J. Proctor and E. Dinerstein. 2004. Ocean of grass: A conservation assessment for the Northern Great Plains. Northern Plains Conservation Network and Northern Great Plains Ecoregion, World Wildlife Fund, Bozeman, MT.

Frank, D. A. and R. D. Evans. 1997. Effects of native grazers on grassland N cycling in Yellowstone National Park. Oecologia 96:157-161.

Frank, D. A., R. S. Innoye, N. Huntly, G. W. Minshall, and J. E. Anderson. 1994. The biogeochemistry of a north-temperate grassland with native ungulates: nitrogen dynamics in Yellowstone National Park. Biogeochemistry 26:163-188.

Frank, D. A. and S. J. McNaughton. 1993. Evidence for the promotion of aboveground grassland production by native large herbivores in Yellowstone National Park. Oecologia 96:157-161.

Frank, D. A. and Y. Zhang. 1997. Ammonia volatilization from a seasonally and spatially variable grazed grassland: Yellowstone National Park. Oecologia 36:189-203.

Franklin, J. F. 1993. Preserving biodiversity: species, ecosystems, or landscapes. Ecological Applications 3: 202-205.

French, N. R., W. E. grant, W. Grodzinski, and D. m. Smith. 1976. Small mammal energetics in grassland ecosystems. Ecological Monographs 46:201-220.

Fuhlendorf, S. D., H. Zhang, T. R. Tunnell, D. M. engle, and A. F. Cross. 2002. Effects of grazing on restoration of southern mixed prairie soils. Restoration Ecology 10:401-407.

Fuhlendorf, S. D. and D. M. Engle. 2001. Restoring heterogeneity on rangelands: ecosystem management based on evolutionary grazing patterns. Bioisceince 51:625-632.

Fuhlendorf, S. D. and D. M. Engle. 2004. Application of the fire-grazing interaction to restore a shifting mosaic on tallgrass prairie. Journal of Applied Ecology. 41:604-614.Fuls 1992.

Fuls, E.R. 1992. Semi-arid and arid rangelands: a resource under siege due to patch-selective grazing. Journal of Arid Environments, 22, 191–193.

Gibson, D. J., and L. C. Hulbert. 1987. Effects of fire, topography and year-to-year climatic variation on species composition in tall-grass prairie. Vegetatio 72:175-182.

Glen-Lewin D. C., L. A. Johnson, T. W. Jurik, A. Akey, M. Leoschke, and T. Rosburg. 1990. Fire in central North American grasslands: vegetative reproduction, seed germination, and seedling establishment. Pp. 28-45 in S. L. Collins and L. L. Wallace (eds.) Fire in North American Tall Grass Prairies. University of Oklahoma Press, Norman.

Goolsby, D. A., W. A. Battaglin, and E. M. Thurman. 1993. Occurrence and transport of agricultural chemicals in the Mississippi River Basin, July through August 1993. U.S. Geological Survey Circular 1120-C. 22 pp.

Gray, L. J. and W. K. Dodds. 1998. Structure and dynamics of aquatic communities. Knapp, A. K.; Briggs, J. M.; Hartnett, D. C., and Collins, S. L., editors. Grassland dynamics: long-term ecological research in tallgrass prairie. New York, NY: Oxford University Press. pp. 177-189.

Gray, L. J.; G. L. Macpherson, J. K. Koeliker, and W. K. Dodds. 1998. Hydrology and aquatic chemistry. Knapp, A. K.; Briggs, J. M.; Hartnett, D. C., and Collins, S. L., editors. Grassland dynamics: long-term ecological research in tallgrass prairie. New York, NY: Oxford University Press. pp. 159-176.

Green, R. A. and J. K. Detling. 2000. Defoliation-induced enhancement of total aboveground nitrogen yield of grasses. Oikos 91:280-284.

Groffman, P. M., C. W. Rice, and J. M. Tiedje. 1993. Denitrification in a tallgrass prairie. Ecology 74:855-862.

Gross, J.E. 2003. Developing Conceptual Models for Monitoring Programs. National Parks Service Inventory and Monitoring Program, Ft. Collins, CO.

Haley, J. E. 1929. Grass fires of the southern great Plains. West Texas Historical Association Year Book 5:23-42.

Halvorson, C. H. 1984. Long-term monitoring of small vertebrates: a review with suggestions. Pp 11-25 in J. Johnson, J. Franklin, and R. Krebill, coordinators. Research natural areas: Baseline monitoring and management. Gen. Tech. Rpt. INT 173. Forest Service Intermountain Forest and Range Experiment Station, Ogden, Utah.

Hansen, R. M. and I. K. Gold. 1977. Blacktail prairie dogs, desert cottontails, and cattle trophic relations on shortgrass range. Journal of Range Management 30:210-213.

Hart, R. H., and J. A. Hart. 1997. Rangelands of the Great Plains before European settlement. Rangelands 19(1):4-11.

Harnett, D. C. and K. H. Keeler. 1995. Population Processes. Joern, A. and Keeler, K., editorsNew York, NY: Oxford University Press. pp. 82-99.

Hartnett, D.C., K. R. Hickman,and L. E. Fischer-Walter. 1996. Effects of bison grazing, fire, and topography on floristic diversity in tallgrass prairie. Journal of Range Management. 49:413–420.

Harwell, M. A., V. Myers, T. Young, A. Bartuska, N. Gassman, J. H. Gentile, C. C. Harwell, S. Appelbaum, J. Barko, B. Causey, C. Johnson, A. McLean, R. Smola, P. Templet, and S. Tosini. 1999. A framework for an ecosystem integrity report card. BioSicence 49: 543- 556.

Heil, G.W., M. J. A. Werger, W. de Mol, D. van Dam and B. Heijne. 1988. Capture of atmospheric ammonium by grassland canopies. Science. Vol. 239, no. 4841, pp. 764-765. 1988.

Herkert, J. R. 1994. The influence of habitat fragmentation on Midwestern grassland bird communities. Ecological Applications 4(3):461-471.

Higgins, K.F. 1986. Interpretation and Compendium of Historical Fire Accounts in the Northern Great Plains. Resource Publication 161. U.S. Department of the Interior, Fish and Wildlife Service, Brookings, SD.

Hoagland, B.W. and F.L. Johnson. 2001. Vascular flora of the CHIC, Murray county, OK. Castanea 66:383–400.

Hobbs, N.T., D.S. Schimel, C.E. Owensby, and D.J. Ojima. 1991. Fire and grazing in tallgrass prairie: contingent effects on nitrogen budgets. Ecology 72: 1374-1382.

Holland, E. A. and J. K. Detling. 1990. Plant response to herbivory and belowground nutrient cycling. Ecology 71:1040-1049.

Holling, C.S. 1978. Adaptive Environmental Assessment and Management. John Wiley and Sons, New York, New York, USA.

Holling, C. S., L. H. Gunderson, and D. Ludwig. 2002. In quest of a theory of adaptive change.Pages 3-22 *in* L. H. Gunderson and C. S. Holling, editors. Panarchy: Understandingtransformations in human and natural systems. Island Press, Washington, D.C.

Hopkins et al. 1948. Some effects of burning upon a prairie in west-central Kansas. Transactions of the Kansas Academy of Science 87:434-437.

Hornaday W. T. 1889. The extermination of the American bison. Report of the U.S. National Museum, 1887-1887, 367-548. Washington, D.C. U.S. National Museum

Howe, H. F. 1994. Managing species diversity in tall-grass prairie: assumptions and implications. Conservation Biology 8:705-712.

Humphrey, R. R. 1958. The desert grassland: A history of vegetation change and analysis of causes. Botanical review 24:193-252.

Huntzinger, T. L. 1996. Surface water: a critical Great Plains resource. In S. Johnson and A. Bouzaher, editors. Conservation of Great Plains ecosystems: current science, future options. Kluwer Academic Press, Dordrecht, The Netherlands.

Inglis, R.R. 2001. Trip report for travel to Washita Battlefield July 16-19, 2001. Water Resources Division.

James, S. W. 1991. Soil, nitrogen, phosphorus, and organic matter processing by earthworms in tall-grass prairie. Ecology 72:2101-2109.

Jaramillo, W. J. and J. K. Detling. 1988. Grazing history, defoliation, and competition: effects on shortgrass production and nitrogen accumulation. Ecology 69:1599-1608.

Jenkins, K., A. Woodward, and E. Schreiner. 2002. A framework for long-term ecological monitoring in Olympic National Park: Prototype for the coniferous forest biome. U.S. Geological Survey – Olympic Field Station. Port Angeles, Washington, USA.

Jenny, H. 1941. Factors of soil formation: a system of quantitative pedology. McGraw-Hill,NewYork, New York.

Jenny, H. 1980. The soil resource: origin and behavior. Springer-Verlag, New York, New York.

Joern, A. and S. B. Gaines. 1990. population dynamics and regulation in grasshoppers. Pp. 415-482 in R. F. Chapman and A. Joern (eds.). Biology of grasshoppers. Wiley, New York.

Johnson, W. C., and S. P. Bratton. 1978. Biological monitoring in UNESCO biosphere reserves with special reference to the Great Smoky Mountains National Park. Biological Conservation 13:105-115.

Jones, K. B. 1986. The inventory and monitoring process. Pp 1-9 in A. Y. Cooperrider, R. J. Boyd, and H. R. Stewart (eds). Inventory and monitoring of wildlife habitat. U.S. Department of Interior Bureau of Land Management. Service Center, Denver, Colorado, USA.

Jordan, D. S. 1891. Report on explorations in Colorado and Utah during the summer 1889, with an account of fishes found in each of the river basins examined. U. S. Fisheries Commission Bulletin 9:1-40.

Jorgensen, S. E. 1986. Fundamentals of ecological modeling. Elsevier. New York, New York.

Kaufman, G. A. and D. W. Kaufman. 1997. Ecology of small mammals in prairie landscape. Knopf, F. L. and Samson, F. B. Ecology and conservation of Great Plains vertebrates. New York: Springer. pp. 207-243.

Karlen, D. L., M. J. Mausbach, J. W. Doran, R. G. Cline, R. F. Harris, and G. E. Schuman. 1997. Soil quality: A concept, definition, and framework for evaluation. Soil Science Society of America Journal 61: 4-10.

Karr, J. R. 1991. Biological integrity: a long neglected aspect of water resources management. Ecological Applications 1:66-84.

Kerkhoff, A.J., S.N. Martens, G.A. Shore, and B.T. Milne. 2004. Contingent effects of water balance variation on tree cover density in semiarid woodlands. Global Ecology and Biogeography 13: 237-246.

Knapp, A. K. and T. R. Seastedt. 1986. Detritus accumulation limits productivity of tallgrass prairie. Bioscience 36:662-69.

Knapp, A.K., J. M. Blair, J. M. Briggs, S. L. Collins, D. C. Hartnett, L. C. Johnson, and E. G. Towne. 1999. The keystone role of bison in North American tallgrass prairie. Bioscience. 49:39–50.

Knopf, F. L. 1994. Avian assemblages on altered grasslands. Studies Avian. Biol. 15:247-57.

Knopf, F. L. 1996. Prairie legacies-birds. Pages 135-148 *in* F. B. Samson and F. L. Knopf, editors. Prairie conservation: preserving North America's most endangered ecosystem. Island Press, Covelo, Calif.

Knopf, F. L., and F. B. Samson. 1996. Conserving the biotic integrity of the Great Plains. Pages 121-134 in S. R. Johnson and A. Bouzaher, editors. Conservation of the Great Plains ecosystems. Kluwer Academic Publishers, Boston. 434pp.

Knopf, F. L., and F. B. Samson, editors. 1997. Ecology and conservation of Great Plains vertebrates. Ecological Studies 125, Springer. 320pp.

Knopf, F. L., and M. L. Scott. 1990. Altered flows and created landscapes in the Platte River headwaters, 1840-1990. Pages 47-70 in J. M. Sweeney, editor. Management of dynamic ecosystems. North Central Section of the Wildlife Society, West Lafayette, Ind.

Knowles, C.J., C.J. Stoner, and S.P. Gieb. 1982. Selective use of black-tailed prairie dog towns by Mountain Plovers. Condor 84:71-74.

Koford, C. B. 1958. Prairie dogs, whitefaces, and blue grama. Wildlife Monographs 3:6-78.

Koplin, D. W., M. R. Burkart, and E. M. Thurman. 1994. Herbicides and nitrate in near-surface aquifers in the midcontinental United States, 1991. U.S. Geological Survey Water-Supply Paper 2413. 34 pp.

Kreuger, K. 1986. Feeding relationships among bison, pronghorn, and prairie dogs: an experimental analysis. Ecology 67:760-770

Kromm, D.E., and S.E. White. 1992. Groundwater Exploitation in the High Plains. University Press of Kansas, Lawrence, Kansas, USA.

Küchler, A. W. 1986. Potential natural vegetation. Dept. of Interior, U.S. Geological Survey, Reston VA.

Laliberte, A. S., and W. J. Ripple. 2004. Range contractions of North American carnivores and ungulates. BioScience 54(2): 123-138.

Landsberg, J., C. D. James, S. R. Morton, W. J. Muller, and J. Stol. 2003. Trends in abundance and composition of plant species along grazing gradients in Australian rangelands. Journal of Applied Ecology 40:1025–1034.

Lauenroth, W.K. and E. M. Preston. 1984. The effects of SO2 on a grassland: A case study in the Northern Great Plains of the United States. Springer, New York, New York, USA. 207pp.

Lauenroth, W. K., and O. E. Sala. 1992. Long-term forage production of North American steppe. Ecological Applications 2:397-403.

Launchbaugh, J. L. 1973. effects of fire on shortgrass and mixed prairie species. Proceedings of the Tall Timbers Fire Ecology Conference 12:129-151.

Laycock, W. A. 1991. Stable states and thresholds of range condition on North American rangelands: a viewpoint. Journal of Range Management. 44(5):427-433.

Lewis, M. 1961. The Lewis and Clark expedition. Volume 1. J. B. lippincott, Philadelphia, Pennsylvania, USA.

Lewis, H. T. 1973. Patterns of Indian burning in California. Ecology and ethnohistory. Ballena Press Anthropological Papers No. 1. Ballena Press, Menlo Park, California, USA.

Licht, D. S. 1997. Ecology and economics of the Great Plains. U. of Nebraska Press, Lincoln. 225pp.

Likens, G. 1992. An ecosystem approach: its use and abuse. Excellence in ecology, book 3. Ecology Institute, Oldendorf/Luhe, Germany.

Lippert, R. D. and H. H. Hopkins. 1950. Study of viable seeds in various habitats in mixed prairie. Transactions of Kansas Academy of Science 53:355-364.

Lockwood, J. 2004. Tales from a specie's crypt. Conservation in Practice 5(4):20-27.

Longo, P. J., and D. W. Yoskowitz. 2002. Water on the Great Plains: issues and policies. Texas Tech U., Lubbock. 200pp.

Mack, M. N., and C. M. D'Antonio. 1998. Impacts of biological invasions on disturbance regimes. Trends in Ecology and Evolution 13:195-198.

Mattes, J.J. 1969. The Great Platte River Road. Vol. XXV, Nebraska State Historical Society, Lincoln NE.

Matthews, W.J. 1988. North American prairie streams as systems for ecological study. Journal of the North American Benthological Society 7: 387-409.

Matthews, W. J. and E. G. Zimmermann. 1990. Potential effects of global warming on native fishes of the southern Great Plains and the southwest. Fisheries. 15(6):26-32.

Margoluis, R. and N. Salafsky. 1998. Measures of success: designing, managing and monitoring conservation and development projects. Island Press, Washington, D.C.

Martin, S.C. and D. E. Ward. 1970. Rotating access to water to improve semidesert cattle range near water. Journal of Range Management 23:22–26.

McHugh, T. 1958. Social behavior of the American buffalo (*Bison bison bison*). Zoologica 43:1-40.

McNaughton, S. J. 1979. Grassland-herbivore dynamics. In: Sinclair, A. R. E., and M. Norton-Griffiths (eds.) Serengeti: Dynamics of an ecosystem. University of Chicago Press, Chicago, Illinois. Pp. 46-81.

Mead, J. R. 1896. A dying river. Transactions of the Kansas Academy of Sciences. 14:111-112.

Meagher, M. M. 1978. Bison. Pages 123-134 in J. L. Schmidt and D. L. Gilbert, editors. Big game of North America. Stackpole Books, Harrisburg, Pa.

Milbacher, B. S., F. E. Smeins, G. W. Thomas, and C. A. Taylor. 1989. Long-term grass dynamics within a mixed-grass prairie. Pp. 25-28 in Proceedings of the Eleventh North American Prairie Conference, T. B. Bragg and J. Stubbendieck (eds.). University of Nebraska Press, Lincoln.

Milchnuas, D. G. and W. K. Lauenroth. 1993. Quantitative effects of grazing on vegetation and soils over a global range of environments. Ecological Monographs 63:327-366.

Miller, B., G. Ceballas, and R. Reading. 1994. The prairie dog and biotic diversity. Conservation Biology 8:677-681.

Milner, J. Associates, Inc. 2003. Washita battlefield national historic site cultural landscape report: part 2. Task Order T7486010178. Charlottesville, VA.

Mitsch, W. J., and J. G. Gosselink. 2000. Wetlands. Third Edition. John Wiley and Sons, Inc., New York.

Mock, C. J. 1991. Drought and precipitation fluctuations in the Great Plains during the late nineteenth century. Great Plains Research 1:26-57.

Monson, R. K., M. E. Rumpho, and G. E. Edwards. 1983. The influence of inorganic phosphate on photosynthesis in intact chloroplasts from Mesembryanthemum crystallinum L. plants exhibiting C3 photosynthesis or Crassulacean acid metabolism. Planta. 159: 97-104.

Moore, C. T. 1972. Man and fire in the central North American grassland 1535-1890: A documentary historical geography. Ph.D. Dissertation, University of California, Los Angeles.

Muñoz-Erickson, T.A., M.R. Loeser, and B.J. Aguilar-Gonzàlez. 2002. Identifying indicators of ecosystem health for a semiarid ecosystem: a conceptual approach. In van Riper, C., III, and K.L Cole (eds.). The Colorado Plateau: Cultural, Biological, and Physical Research. The University of Arizona Press, Tucson, Arizona, USA.

Nadler, C. T., and S. A. Schumm. 1981. Metamorphosis of South Platte and Arkansas Rivers, eastern Colorado. Physiological Geography. 2:95-115.

Nagel, H. G. 1983. Effect of spring burning date on mixed-prairie soil moisture, productivity, and plant species composition. Pp. 250-263 in C. L. Kucera (ed.) Proceedings of the Seventh North American Prairie Conference. Southwest Missouri State University, Springfield.

Nasatir, A. P. 1952. Before Lewis and Clark. Volumes 1 & 2. St. Louis Historical Documents Foundation. St. Louis, Missouri USA.

National Park Service. 2001. 2001 NPS Management Policies. United States Department of the Interior, National Park Service, Washington, D.C.

National Research Council. 1995. Wetlands: characteristics and boundaries. National Academy Press, Washington, D.C.

Neuenschwander, L. F., H. A. Wright and S. C. Bunting. 1978. The effect of fire on a tobassograss-mesquite community in the rolling plains of Texas. Southwestern Naturalist 23:315-338.

Noon, B. R. 2003. Conceptual issues in monitoring ecological resources. In D.E. Busch and J.C. Trexler, editors. Monitoring Ecosystems: Interdisciplinary Approaches for Evaluating Ecoregional Initiatives. Island Press, Washington, D.C., USA.

Noon, B. R., T. A. Spies, and M. G. Raphael. 1999. Conceptual basis for designing an effectiveness monitoring program. Chapter 2 *in* B. S. Mulder, B. R. Noon, T. A. Spies, M. G.

Noss, R. 1990. Indicators for monitoring biodiversity. *Conservation Biology* 4: 355-364.

O'Meilia, M. E., F. L. Knopf, and J. C. Lewis. 1982. Some consequences of competition between prairie dogs and beef cattle. Journal of Range Management 35:580-585.

Omernick, J. 1987. Ecoregions of the conterminous United States. Annals of Association of American geographers 77:88-125.

O'Neill, R. V., D. L. DeAngelis, J. B. Waide, and T. F. H. Allen. 1986. A hierarchical concept of ecosystems. Princeton University Press, Princeton, New Jersey, USA.

O'Neill, R.V., and A. W. King. 1998. Homage to St. Michael; or, why are there so many books on scale? Pages 3-15 in D.L. Peterson and V. T. Parker, editors. Ecological Scale: Theory and Applications. Columbia University Press. New York, NY.

Ostlie, W. R., R. E. Schneider, J. M. Aldrich, T. M. Faust, R. L. B. McKim, and S. J. Chaplin. 1997. The status of biodiversity in the Great Plains. The Nature Conservancy, Minneapolis, Minnesota, USA.

Parton, W. J., W. K. Lauenroth, and F. M. Smith. 1981. Water loss from a short-grass steppe. Agricultural Meteorology 24:97-109.

Perkins, D. W., H. Sosinski, K. Cherwin, and T. F. Zettner. 2005. Southern Plains Network Vital Signs Monitoring Plan: Phase I. National Park Service, Southern Plains Network, Johnson City, TX, USA. 79 pp. plus appendices.

Peden, D. G., G. M. Van Dyne, R. W. Rice, and R. M. Hansen. 1974. The trophic ecology of *Bison bison* L. on shortgrass plains. Journal of Applied Ecology 11:489-498.

Peterjohn, B.G., and Sauer, J.R. 1999. Population status of North American grassland birds from the North American Breeding Bird Survey, 1966-1996. Studies in Avian Biology 19: 27-44.

Peterson, G. A., and C. V Cole. 1996. Productivity of Great Plains soils: past, present and future. Pages 325-342 in S. Johnson and A. Bouzaher, editors. Conservation of Great Plains ecosystems: current science, future options. Kluwer Academic Press, Dordrecht, The Netherlands.

Pickett, S.T.A., V. T. Parker, and P. L. Fiedler. 1992. The new paradigm in ecology: implications for conservation biology above the species level. Conservation Biology: The Theory and Practice of Nature Conservation, Preservation and Management (eds P.L. Fiedler & S.K. Jain), pp. 65–88. Chapman& Hall, New York, NY.

Pieper, R. D. 1990. Overstory-understory relations in pinyon-juniper woodlands in New Mexico. Journal of Range Management. 43(5):413-415.

Plumb, G. E. and J. L. Dodd. 1993. Foraging ecology of bison and cattle on a mixed prairie: implications for natural area management. Ecological Applications 3:631-643.

Pohlman, D. 2005. Air quality monitoring considerations for the Northern Great Plains Network parks. A report submitted to the Northern Great Plains I&M Program. Midwest Regional Office, National Park Service, St. Paul MN. March 2005.

Polley, H. W. and J. K. Detling. 1988. Herbivory tolerance of *Agropyron smithii* populations with different grazing histories. Oecologia 77:261-267.

Polley, H. W. and J. K. Detling. 1990. Grasing-mediated differentiation in Agropyron smitthii: evidence from populations with different grazing histories. Oikos 57:326-332.

Popper, D. E., and F. J. Popper. 1987. The Great Plains: from dust to dust. Planning 53(6):12-18.

Popper, D. E., and F. J. Popper. 1994. The buffalo commons: a bioregional vision of the Great Plains. Landscape Arch., 84(4):144.

Quinn, J.F., and C. Van Riper III. 1990. Design considerations for national park inventory databases. Pp 5-14 in C. Van Riper III et al. ed. Examples of Resource Inventory and Monitoring in National Parks of California. Proc. of the Third Biennial Conference on Research in California's National Parks, September 13-15, 1990. University of California, Davis, California. 268 pp.

Rabinowitz, D. 1981. Buried viable sees in a North American tallgrass prairie: the resemblance of their abundance and composition to dispersing seeds. Oikos 36:191-195.

Reed, J., M. Schmitz, B. Simpson, and L. Hudson. 1999. Natural and Cultural Resource Management Plan: Pecos National Historical Park. Pecos, NM.

Reichman, O. J., J. H. Benedix, Jr., and T. R. Seastadt. 1993. Distinct animal-generated edge effects in a tall-grass prairie community. Ecology 74:1281-1285.

Rice, R. K. 1989. Impact of seed banks on grassland community structure and population dynamics. In M. A. Leck, V. T. Parker, and R. L. Simpson (eds.). Ecology of soil seed banks. Academic Press, Orlando, Florida, USA.

Rickletts, T.H., E. Dinerstein, D.M. Olsen, C.J. Loucks, W. Eichbaum, D. DellaSala, K. Kavanagh, P. Hedao, P.T. Hurley, K.M. Carney, R. Abel, and S. Waiters. 1999. Terrestrial ecoregions of North America. Island Press, Washington, D.C.

Riegel, A. 1941. Life history and habits of blue grama. Transactions of Kansas Academy of Science 44:76-85.

Risser, P.G. 1990. Landscape processes and the vegetation of the North American grassland. Pages 133-146 in S.L. Collins and L.L. Wallace, eds. Fire in North American tallgrass prairies. University of Oklahoma Press, Norman, OK.

Risser, P. G., E. C. Birney, H. D. Blocker, S. W. May, W. J. Parton, and J. A. Wiens. 1981. The true prairie ecosystem. Hutchinson Ross Publishing Co., Stroudsburg, PA. 557pp.

Roe, F. G. 1951. The North American buffalo. University of Toronto Press, Toronto, Ontario, Canada.

Roman, C. T., and N. E. Barrett. 1999. Conceptual Framework for the Development of Longterm Monitoring Protocols at Cape Cod National Seashore. USGS Patuxent Wildlife Research Center, University of Rhode Island, Providence, Rhode Island.

Sampson, R. N. 1981. Farmland or wasteland: a time to choose: overcoming the threat to America's farm and food future. Rodale Press, Emmaus, Pa. 481 pp.

Samson, F.B. 1980. Island biogeography and the conservation of prairie birds. Proceeding, North American Prairie Conference 7: 293-305.

Samson, F. B., and F. L. Knopf. 1994. Prairie conservation in North America. BioScience 44:418-421.

Samson, F. B., F. L. Knopf, and W. R. Ostlie. 1998. Grasslands. Pages 437-472 in M. J. Mac, P. A. Opler, C. E. Puckett Haecker, and P. D. Doran, eds. Status and Trends of the Nation's Biological Resources, Vol. 2. U.S. Department of the Interior, U.S. Geological Survey.

Samson, F. B.. F. L. Knopf, and W. R. Ostlie. 2004. Great Plains ecosytems: past, present, and future. Wildlife Society Bulletin. 32(1):6-15.

Sanders, R. W. and M. Gallyoun. 2004. Vascular plants of Lyndon B. Johnson National Historical Park Blanco and Gillespie Counties, Texas. Results of a 2002 floristic inventory and related research and reviews. The Nature Conservancy, Botanical Research Institute of Texas and National Park Service. 51pp.

Sanders, R. W. 2005. Update to: Vascular plants of Lyndon B. Johnson National Historical Park Blanco and Gillespie Counties, Texas. Results of a 2005 supplemental floristic inventory. Botanical Research Institute of Texas and the National Park Service. 36pp.

Sanders, R. W. and M. Gallyoun. 2004. Vascular plants of Lyndon B. Johnson National Historical Park Blanco and Gillespie Counties, Texas. The Nature Conservancy 60 pp.

Sauer, C. O. 1950. Grassland climax, fire and man. Journal of Range Management 3:16-20.

Savage D.A. and L.A. Jacobson. 1935. The killing effect of heat and drought on buffalo grass and blue grama grass at Hays. Kansas Journal American Society of Agronomy 27: 566–582

Schlesinger, W. H., J. F. Reynolds, G. L. Cunningham, L. F. Huenneke, W. M. Jarrell, R. A. Virginia, and W. G. Whitford. 1990. Biological feedbacks in global desertification. Science 247 (4946): 1043-1048 1990

Schmiel, D. S., W. J. Parton, F. J. Anderson, R. G. Woodmansee, R. L. Senft, and M. A. Stillwell. 1986. The role of cattlein the volatile loss of nitrogen from the shortgrass steppe. Biogeochemistry 2:39-52.

Schwartz, C. C. and J. E. Ellis. 1981. Feeding ecology and niche separation in some native and domestice ungulates on the shortgrass prairie. Journal of Applied Ecology 18:343-353.

Scott M. L., J. M. Friedman and G. T. Auble. 1996. Fluvial Process and the Establishment of Bottomland Trees. Geomorphology 14:327-339.

Seastedt, T. R., R. A. Ramundo, and D. C. Hayes. 1988. Maximization of soil animals by foliage herbivory: empirical evidence, graphical and conceptual models. Oikos 51:243-248.

Seastedt, T. R. 2001. Soils. Pages 157-173 *in* W. D. Bowman and T. R. Seastedt, editors. Structure and function of an alpine ecosystem: Niwot Ridge, Colorado. Oxford University Press, New York, New York.

Seastedt, T.R. 2002. Grasslands. Pages 219-239 *in*: Baron, J. (ed). Rocky Mountain Futures: An ecological Perspective. Island Press, Covelo CA.

Seybold, C. A., J. E. Herrick, and J. J. Brejda. 1999. Soil resilience: A fundamental component of soil quality. Soil Science 164: 224-234.

Shantz, H. L. 1917 Plant succession on abandoned roads in eastern Colorado. Journal Ecology 5:19-42..

Sharrow, S. H. and H. A. Wright. 1977. Proper burning intervals for tobasagrass in west Texas based on nitrogen dynamics. Journal of Range Management 30:343-346.

Simons, S. B., and T. R. Seastedt. 1999. Decomposition and nitrogen release from foliage of cottonwood (*Populus deltoides*) and Russian-olive (*Eleaegnus angustifolia*) in a riparian ecosystem. Southwestern Naturalist 44:256-260.

Simms, P. L. 1988. Grasslands. Pages 265-286 *in* M. G. Barbour and W. D. Billings, editors. North American terrestrial vegetation. Cambridge University Press, New York.

Sims, P. L., and J. S. Singh. 1971. Herbage dynamics and net primary production in certain ungrazed and grazed grasslands in North America. In N. R. French, editor. Preliminary Analysis of Structure and Function in Grasslands. Range Science Dept. Sci. Series no. 10, Colorado State Univ., Fort Collins. 387pp.

Smith County Pioneer. 1877. Smith Center, Kansas *in* Fleharty, E. D. Wild animals and settlers on the Great Plains. University of Oklahoma Press, Norman, Oklahoma.

Stafford Smith, D. M. and S. R. Morton. 1990. A framework for the ecology of arid Australia. Journal of Arid Environments 18:255-278.

Starfield, A.M. 1997. A pragmatic approach to modeling for wildlife management. Journal of Wildlife Management 61:261-270.

Starfield, A. M., K. A. Smith, and A. L. Bleloch. 1994. How to model it: problem-solving for the computer age. Burgess Int., Edina, Minnesota.

Starfield, A. M., and A. L. Bleloch. 1986. Building models for conservation and wildlife management. Macmillan Publishing Co., New York, New York.

Steinauer, E. M. and S. L. Collins. 1996. Prairie ecology-the tallgrass prairie. Pp. 39-52 *in* F. B. Samson and F. L. Knopf, (eds.). Prairie Conservation. Preserving North America's most endangered ecosystem. Island Press, Washington DC, and Corvello, Califronia, USA.

Steuter A. A., E. M. Steinauer, G. P. Hill, P. A.. Bowers, and L. L. Tieszen. 1995. Distribution and diet of bison and pocket gophers in a sandhills prairie. Ecological Applications 5:756-766.

Steuter, A. A. and H. A. Wright. 1983. Spring burning effects on redberyy juniper-mixed grass habitats. Journal of Range Management 36:161-164.

Stringham, T.K., W.C. Krueger and P.L. Shaver. 2003. State and transition modeling: A process based approach. J. Range Management 56:106-113.

Stubbendieck, J. 1988. Historical development of native vegetation on the Great Plains. Pages 21-28 in Impacts of the Conservation Reserve Program in the Great Plains: Symposium proceedings, September 16-18, 1987, Denver, Colorado.

Stubbendieck, J., T. R. Flessner, C. H. Butterfield, and A. A. Steuter. 1993. Establishment and survival of the endangered blowout penstemon. Great Plains Research 3:3-19.

Tausch, R.J. and P.T. Tueller. 1990. Foliage biomass and cover relationships between tree- and shrub-dominated communities in pinyon-juniper woodlands. Great Basin Naturalist 50: 121-134.

Thurow, T. L., W. H. Blackburn, and C. A. Taylor. 1988. Infiltration and interrill erosion responses to selected livestock grazing strategies, Edwards Plateau, Texas. Journal of Range Management 41:296-302.

Tilman, D. and A. El Haddi. 1992. Drought and biodiversity in grasslands. Oecologia 89:257-264.

Tobler, M.W., R. Cochard. and P. J. Edwards. 2003. The impact of cattle ranching on large-scale vegetation patterns in a coastal savanna in Tanzania. Journal of Applied Ecology,40, 430–444.

Tomanek, G. W. and F. W. Albertson. 1957. Variations in cover, composition, production, and roots of vegetation in two prairies in western Kansas. Journal of Range Management 6:299-306.

Tripathi, R. S. and J. L. Harper. 1973. The comparative biology of Agropyron repens L. (Beauv.) and A. canninum L. (Beauv.) I. The growth of miced populations established from tillers and from seeds. Journal Ecology 61:353-368.

Turner, M. G., R. H. Gardner, and R. V. O'Neill. 2001. Landscape ecology in theory and practice: pattern and process. Springer-Verlag, New York, New York.

Turner, M. G., and R. V. O'Neill. 1995. Exploring aggregation in space and time. Pages 194-208 in C. G. Jones and J. H. Lawton (eds.). Linking species and ecosystems. Chapman and Hall, New York, NY.

U.S. National Park Service. 2003. Ozone Sensitive Plant Species on National Park Service and US Fish and Wildlife Service Lands. NPS D1522. Natural Resource Report NPS/NRARD/NRR-2003/01. Air Resources Division. Denver, CO. 21 pp. (Available at www2.nature.nps.gov/ard/pubs/index.htm)

Umbanhowar, C. E. 1996. Recent fire history of the northern Great Plains. American Midland Naturalist 135:115-121.

Uresk, D. W. and D. B. Paulson. 1988. Estimated carrying capacity for cattle competing with prairie dogs and forage utilization in western South Dakota. Pp. 387-390. In Symposium on management of amphibians, reptiles, and small mammals in North America. U.S. Department of Agriculture, Forest Service, Washington D. C.

Vannote, R.I., G.W. Minshall, K.W. Cummings, J.R. Sedell, and C.E. Cushing. 1980. The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences 37:120-137.

Vanoni, V.A. (ed.). 1975. Sedimentation Engineering. American Society of Civil Engineers, New York. 620-625

Vitousek, P. M. 1990. Biological invasions and ecosystem processes: towards an integration of population biology and ecosystem studies. Oikos 57:7-13.

Vitousek, P. M. 1994. Beyond global warming: ecology and global change. Ecology 75: 1861- 1876.

Vitousek, P. M., L. R. Walker, L. D. Whiteaker, D. Mueller-Dombois, and P. A. Matson. 1987. Biological invasion by *Myrica faya* alters ecosystem development in Hawaii. Science 238: 802-804.

Walker, B. 1995. Conserving biological diversity through ecosystem resilience. Conservation Biology 9: 747-752.

Walker, L. R., and F. S. Chapin, III. 1987. Interactions among processes controlling successional change. Oikos 50:131-135.

Walter, H. 1975. Climate diagram maps of the individual continents of the world and the ecological climatic regions of the earth. Springer-Verlag, New York, New York, USA.

Watkinson, A.R. and S. J. Ormerod. 2001. Grasslands, grazing and biodiversity: editors' introduction. Journal of Applied Ecology, 38, 233–237.

Weaver, J. E. 1943. Resurvey of grasses, forbs and underground plant parts at the end of the great drought. Ecol. Monogr. 13:63-117.

Weaver, J. E. 1954. North American prairie. Johnsen Publishing Co., Lincoln NE.

Weaver, J.E. 1968. Prairie plants and their environment. University of Nebraska Press, Lincoln, NE.

Weaver, J. E. and F. W. Albertson. 1956. Grasslands of the Great Plains: their nature and use. Johnsen Publishing, Lincoln, Nebraska, USA.

Weaver, J. E. and I. M. Mueller. 1942. Role of seedlings in recovery of Midwestern range from drought. Ecology 23:275-294.

Weaver, T., E.M. Payson, and D.L. Gustafson. 1996. Prairie ecology—the shortgrass prairie. Pp. 67–75 in F.B. Samson and F.L. Knopf, eds. Prairie Conservation. Island Press, Washington, D.C.

Wedel, W. R. 1986. Central Plains prehistory: Holocene environments and culture change in the Republican River basin. University of Nebraska Press, Lincoln.

Westoby, M., B. Walker, and I. Noy-Meir. 1989. Opportunistic management for rangelands not at equilibrium. Journal of Range Management 42:266-274.

Whicker, A. D. and J. K. Detling. 1988. Ecological consequences of prairie dog disturbances. BioScience 38:778-785.

Whisenant, S. G. 1999. Repairing damaged wildlands: a process-oriented, landscape-scale approach. Cambridge University Press, Cambridge. 312 pp.

White, E. M., and J. K. Lewis. 1967. Recent gully formation in prairie areas of the Northern Great Plains. Plains Anthropologist 12:318-322.

White, P.S., and S.P. Bratton. 1980. After preservation: philosophical and practical problems of change. Biological Conservation 18:241-255.White and Lewis. 1967.

Whitford, W. G. 1986. Decomposition and nutrient cycling in deserts. Pp. 93-117 in W. G. Whitford (ed.). Pattern and process in desert ecosystems. University of New Mexico Press, Albuquerque.

Whitford, W. G. 2002. Ecology of desert systems. Academic Press, San Diego. 343 pp.

Wikle, T., M. Nicholl, T. Brown, J. Nord, R. Parker, and D. Weeks. 1998. Water resources management plan - Chickasaw National Recreation Area. 121 pages.

Wilcox, B.P. and D.W. Davenport. 1995. Juniper encroachment: potential impacts to soil erosion and morphology. Interior Columbia Basin Ecosystem Management Project. 1-16.

Wilhite, D. A. and R. O. Hoffman. 1979. Drought in the Great Plains: A bibliography. Institute of Agriculture and Natural Resources, University of Nebraska, Lincoln, Nebraska, USA.

Williams, J., and P. Diebel. 1996. The economic value of prairie. Pages 19-35 *in* F. B. Samson and F. L. Knopf, editors. Prairie conservation: preserving North America's most endangered ecosystem. Island Press, Covelo, Calif.

Williams, W. G., and M. G. Wolman. 1986. Effects of dams and reservoirs on surfacewater hydrology changes in rivers downstream from dams. Pages 83-88 in D. W. Moody, E. G. Chase, and D. R. Aroson, editors. National water summary 1985hydrologic events and surface water reservoirs. U.S. Geological Survey Water Supply Paper 2300.

Wink, R. L. and H. A. Wright. 1973. Effects of fire on an ashe juniper community. Journal of Range Management 26:236-329.

Woodley, S. 1993. Monitoring and measuring ecosystem integrity in Canadian National Parks. Pages 155 – 175 IN S. Woodley, J. Kay, and G. Francis, editors. Ecological Integrity and the Management of Ecosystems. St. Lucie Press. Delray Beach, FL.

Woodward, A., KI. J. Jenkins and E. G. Schreiner. 1999. The role of ecological theory in long term ecological monitoring: report of a workshop. Natural Areas Journal 19:223-233.Wright. 1974.

Wright, H. A. 1974. Effect of fire on southern mixed prairie grasses. Journal of Range Management 27:417-419.

Wright, P. A. 2002. Monitoring for forest management unit scale sustainability: The Local Unit Criteria and Indicators Development (LUCID) test. Technical Edition. USDA Forest Service, Inventory and Monitoring Institute Report No. 4. 370 pages.

Wright, H. A. and A. W. Bailey. 1982. Fire ecology: United States and Southern Canada. John and Wiley Sons, New York, New York, USA.

Yeaton, R. I. and K. J. Esler. 1990. The dynamics of a succulent Karoo vegetation: a study of species association and recruitment. Vegetatio 88:103-113.

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